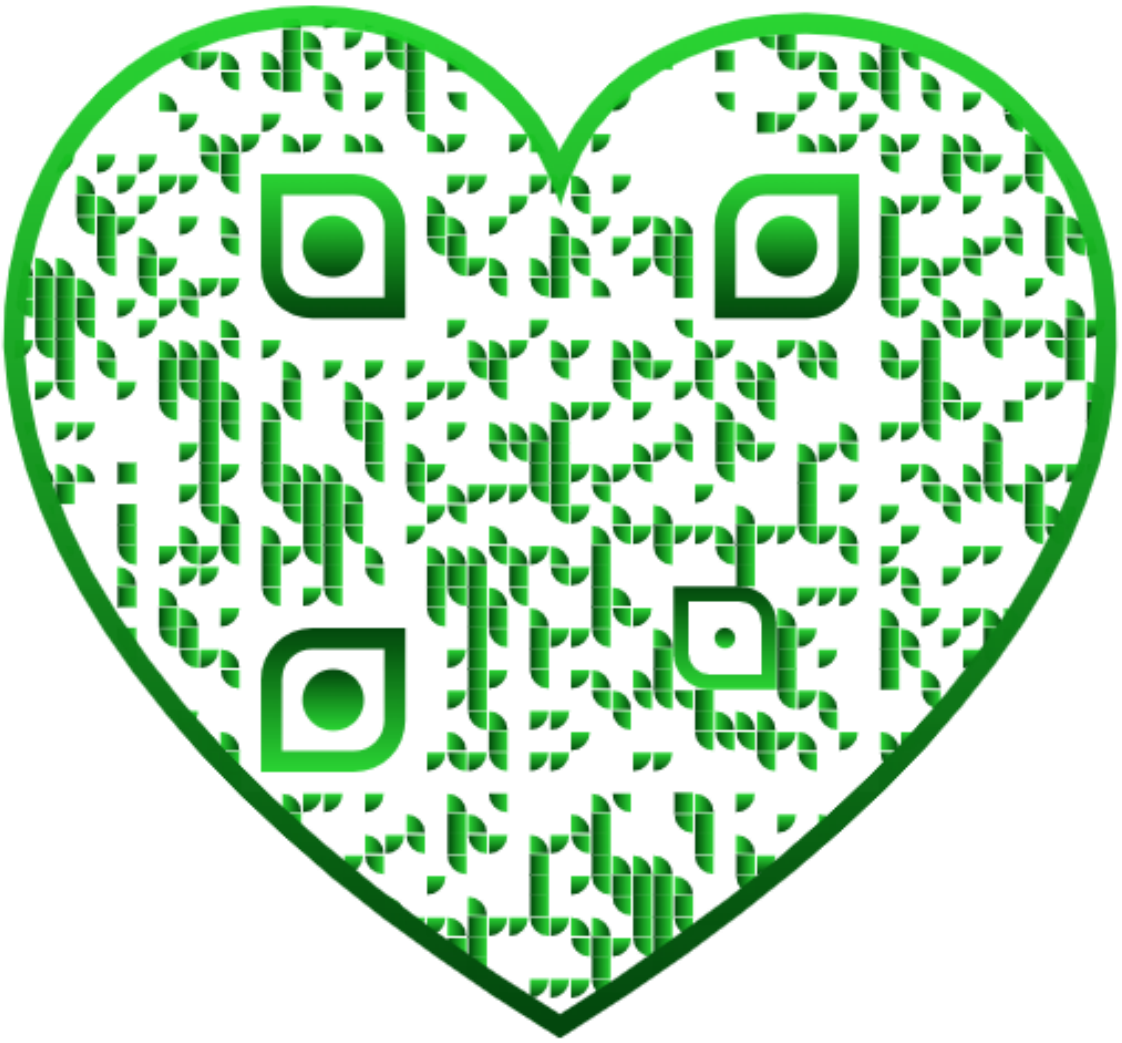
CHARLES RIVER EDITORS
ANCIENT GREEK TECHNOLOGY
The History and Legacy of the Technological Advances Made in Greece during Antiquity



Ancient Greek Technology: The History and Legacy of the Technological Advances Made in Greece during Antiquity

By Charles River Editors

A model of an ancient watermill

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Introduction

Ancient Greek Technology

A picture of the salvaged Antikythera Mechanism

"What I would prefer is that you should fix your eyes every day on the greatness of Athens as she really is, and should fall in love with her. When you realize her greatness, then reflect that what made her great was men with a spirit of adventure, men who knew their duty, men who were ashamed to fall below a certain standard. If they ever failed in an enterprise, they made up their minds that at any rate the city should not find their courage lacking to her, and they gave to her the best contribution that they could." – *The Funeral Oration of Pericles*, quoted by Thucydides

Dominated to this day by the sprawling white marble complex of the Acropolis, Athens is a city which is immensely and rightly proud of its past.

For a period of roughly three centuries, the polis of Athens stood, if not in a position of unchallenged supremacy among the cities of Hellas, then at the very least among its three most important polities. Its fledgling Empire, though small by the standards later set by Alexander or the Romans, or even by those of its ancient enemy Persia, nonetheless encompassed cities as far afield as Asia Minor and Southern Italy, a remarkable fact considering such expansion was achieved by the inhabitants of a single city and its immediate surroundings, rather than by an entire nation.

For much of its history, the Athenian navy was the single mightiest force in the Mediterranean, having defeated the overwhelming might of Persia in pitched battle upon the open sea numerous times. The Athenian army itself, though subordinate to its naval power – a sop to the fact that it was trade and empire-building that had made Athens rich – was nothing to be sneered at, as it succeeded in meting out a humiliating defeat to Darius's Persians at Marathon.

Yet despite a martial tradition that, if taken as a whole, was second to none save the Spartans, Athens is chiefly remembered for two reasons: its political system, which would in time form the nucleus of all Western democratic systems of government, and the remarkable number of outstanding individuals which, during the Golden Age of Athens, lived and flourished in the enlightened city-state. The Ancient Athenians formed the backbone of the West's entire culture, from the arts to philosophy and everything inbetween.

In virtually all fields of human endeavor Athens was so much at the forefront of dynamism and innovation that the products of its most brilliant minds remain not only influential but entirely relevant to this day. In the field of medicine, the great physician Hippocrates not only advanced the practical knowledge of human anatomy and care-giving but changed the entire face of the medical profession. The great philosophers of Athens, men like Aristotle, Socrates, and Plato, interrogated themselves with startling complexity about the nature of good and evil, questioned the existence of divinity, advocated intelligent design, and went so far as to argue that all life was composed of infinitesimal particles. Great architects and sculptors such as Phidias produced works of art of such breathtaking realism and startling dynamism that they later formed the driving force behind the resurgence of sculpture

during the Renaissance and served as masters to artists such as Michelangelo, Bernini, and Donatello. The plays of dramatists such as Aristophanes not only displayed an acerbic wit and a genius for political satire so pronounced that their works continue to be performed – and topical – to this day, but served as the inspiration for virtually all playwrights from Shakespeare to the present day. And this does not take into account the host of equally brilliant mathematicians, natural philosophers, historians, astronomers and politicians that the city's great schools nurtured and produced.

The flowering of Greek civilization was further made possible by an increase of trade between the cities and with other civilizations. Trade became a major occupation on account of the scarcity of agricultural land in the largely mountainous regions of the Balkan peninsula. The polis of Athens, in particular, assumed economic dominance in the Aegean in from the sixth-century BC. The consequent increase in wealth, resources and population made a cultural renaissance possible. Commerce, in turn, led to the rise of an affluent aristocratic class which had the leisure to devote itself to learning, philosophy, and art. It also led to an industrial class of freemen who were artists and craftsmen.

Religion also played a role in the development of Greek culture and technology. The ancient Greeks worshipped a multiplicity of gods, the chief of which dwelt on Mount Olympus in the first mountainous region of central Greece. The city-states would regularly send athletes to compete in the Olympic Games in their honor. Each city-state, however, had their own particular god: Athena was honored at Athens; Apollo at Delphi; Poseidon at Corinth; Zeus at Olympia, and so forth. Sculptures, temples and other buildings were built in honor of the gods who were believed to control the forces of nature. The truly great benefit that the gods gave the Greeks was something they did not have, and that was a sense of meaning and purpose to human action and to the natural world of which men and women were a part. For the ancient Greeks, the gods were capricious beings subject to the same passions, emotions, and vicissitudes as humans were, and no more enlightened as to the nature of existence and the path to a good and happy life. The new class of wealthy men who had the leisure to think stepped in where religion refused to go. Thales of Miletus (c.524 – 546 BCE), named by the classicist John Burnet "the first scientist," observed the natural world and

sought rational explanations for it. From him a tradition emerged which explored the world and the actions of humans through natural science, reason, mathematics, metaphysics, and ontology. After Thales a stream of philosophers, mathematicians and engineers emerged including names that are well known today, including Plato, Aristotle, Socrates, Pythagoras, Archimedes, Heraclitus, Epicurus, Diogenes, and Plutarch.

When considering the ancient Greek philosophers and their contribution to civilization it must be remembered that for them there was no separation of disciplines as we have them today. Philosophy was considered an attempt to understand the entire cosmos and not just a part of it. And so it was that every aspect of life and every observable thing might be considered under the umbrella of philosophy, including technology and art. Indeed, it was the ancient Greek philosophers who devised the very concept of technology. Techne, meaning art or craft knowledge, was conceived of as an attempt to imitate the natural order. Plato, in particular, argued that the cosmos was created by the divine craftsmen or Demiurge according to the eternal, immaterial, pre-existent forms, rather as an artist and or engineer creates a work according to a blueprint. He argued that a craftsman imitates the Demiurge and in so doing accomplishes something divine. To the ancient Greeks, the cosmos was ordered and harmonious. Consequently, reason and intellect were considered the architects of all art and craftsmanship. The absolute perfection of form was sought in everything and the Greek passion for simplicity, elegance, harmony, and beauty is to be found everywhere, particularly in architecture.

Ancient Greek Technology: The History and Legacy of the Technological Advances Made in Greece during Antiquity looks at how Greek civilization developed, and the various technological advances that resulted. Along with pictures depicting important people, places, and events, you will learn about Greek technology like never before.

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The Development of Greek Civilization

According to the archaeological evidence uncovered on the site of ancient Sparta (and its immediate surroundings within the valley of the Eurotas), the region was inhabited at least from the Neolithic Period. The valley of the Eurotas constituted a natural strongpoint, as it was (and to some extent still is) a wide, fertile plain, watered by the Eurotas river and ringed with high, virtually impassable peaks that could only be penetrated by a handful of high, easily defensible passes, something which contributed greatly to Sparta's subsequent ascendancy. However, the original settlers appear to have been

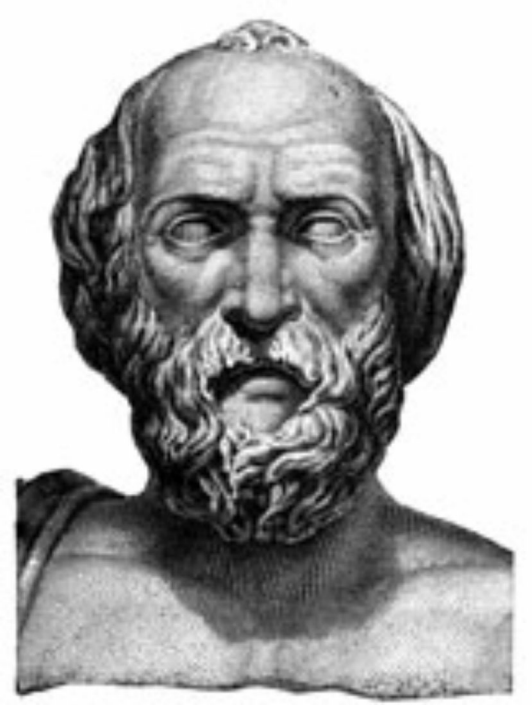
supplanted by what Herodotus refers to as the Dorian Invasion, when a fair-haired tribe from Macedonia supposedly descended into southern Greece and the Peloponnese, displacing the local population approximately half a century after the Trojan War. According to several prominent scholars, however, Herodotus's evidence is to be discounted as he wrote based on myth and hearsay, hundreds of years after the events he accepts as creditable fact.

Another theory is that the Dorian people were already present in large numbers within the Peloponnese but formed the backbone of a downtrodden servile class, and the Dorian Invasion was actually an uprising which led to the overthrow of the established rulers. Whichever theory is correct, however, what is certain is that, in their own minds, the Spartans were fiercely Dorian, spoke a Doric dialect, and considered themselves quite distinct from their Attic rivals from Athens.

As Homer suggests, it is likely that during the period of Mycenean predominance, which ended around approximately 1200 BCE, Sparta was subservient to Mycenae – as evidenced by the fact that Menelaus, king of Sparta, is required to pay tribute to his older brother, and supreme ruler, Agamemnon. However, following the collapse of Mycenae, archaeological evidence suggests a marked increase in the size of the four settlements which would eventually be assimilated into classical Sparta, a consequence both of apparent stability in the area and the fact that the valley of the Eurotas was by far the most fertile region in the Peloponnese, thus promoting agrarian expansion and a population boom.

Between roughly 1000 and 800 BCE. Sparta seems to have enjoyed a period of prosperity and growth, although historical sources from this period are non-existent and what was written down about it subsequently is, to put it charitably, sparse. What does appear certain is that between the 8th and 7th centuries BCE, Sparta suffered from a period of intense factionalism which led to a state of quasi-lawlessness and disunity. It is likely that this was a cause of the assimilation of four villages – Pitana, Limnai, Mesoa and Konoura – into the polity of Sparta, a process which evidently caused significant issues with the stability of the Eurotas valley region as each village had its own "kings" and entrenched ruling classes, all vying for supremacy in the new social order. It is a popular theory that Sparta's famous

“double kings” system, whereby two monarchs (much like the subsequent Roman consuls) shared equal amounts of power so that, if one were killed in battle, the Spartan state would not find itself leaderless, originated during this period: the villages of Pitana and Mesoa had formed a faction which vied for control of Sparta with Limnai and Konoura, and it seems likely that the leaders of these two twin factions eventually became Sparta’s dual monarchs. However, this period of instability is notable chiefly because, according to legend, it was during this time (according to Herodotus and Thucydides, during the reign of King Charillos) that Lycurgus the Law-Giver rose to power.



Bust of Lycurgus

It is hard to separate the myth of Lycurgus from the real man, and indeed many scholars doubt he ever even existed. However, to the Spartans, he was a very real figure indeed. Far from being a mythological being that was most likely a figurehead for a collection of reformers and monarchs, he was the foundation of all that it meant to be a Spartan. His famous reforms established the bedrock of classical Sparta, enjoining (among other things) all Spartan males who possessed a farm whose wealth was sufficient to maintain their upkeep to devote themselves solely to the practice of war and the

inextricably linked field of athletics. Though the Olympics of ancient Greece were a harmonious event during which time no war could be waged, all events remained fiercely bellicose; the armoured sprint, the foot race, wrestling, javelin-throwing, discus throwing, boxing and the pentathlon were all meant to prepare a man for battle.

Lycurgus also supposedly promoted clean, simple living and the abandonment of all luxuries both personal and of the state, allowing the Spartans the one “foible” of growing their hair long. The argument in favor of these prohibitions was that no other adornment made a good-looking man more handsome or an ugly one more terrifying.

Lycurgan reforms also granted Spartan women an unprecedented amount of freedom, and though they had no formal political power, they were encouraged to speak their minds openly in public assembly.

Uniquely among other Greek states, the Spartans also lacked a currency. Sparta was virtually economically self-sufficient in terms of produce and craft expertise, and the Laws of Lycurgus stated that currency debased men, who would then in turn only seek its amassment; better, then, to dispose of it altogether. More controversially, the reforms also encouraged the widespread exposure of newborn children; male children of Spartan citizens in particular. If a baby looked to be too sickly, weak or malformed to endure the trial of the *agoge* (the Spartan military academy and allegedly another of Lycurgus’s innovations), then the baby was as often as not abandoned to die.

The Laws of Lycurgus, regardless of whether they were the product of a single man’s imagination or the result of a drawn-out political process, gave Sparta much-needed stability. In the wake of the quelling of its internecine wars, Sparta began to devote itself to the subjugation of its neighbouring territories, and the expansion of its influence throughout the entire Peloponnese. During the aftermath of the Lycurgan reforms, Sparta waged several successful wars against the neighboring (but ethnically distinct) Arcadians, and their fellow Doric Argives. The wars were a brutal affair in which hundreds or perhaps thousands of the defeated are said to have been put to the sword, displaced or enslaved, but the Spartans emerged triumphant. By around 750 BCE, they had added Amyclae, Pharis and Geronthrae to their domains, ensuring control of the entire upper Eurotas valley, in a war that

was less about one *polis* (city-state) against the other than it was about one ethnic group attempting to wipe the other out. In this case, the Doric tribes wishing to exterminate the neighbouring Achaeans, who had been the ascendant group, by and large, since before the Trojan War. The success of Spartan arms in this war, and the ruthlessness with which they pursued it, first established the basis for the Spartan tradition of victory, which would in subsequent centuries become so cemented as to be virtually ingrained in both their own psyche and that of all of Greece.

This military predominance was further cemented when, sometime between 750 and 650 BCE, two successive wars were waged by the Spartans against their immediate neighbours, the polity of Messenia. Though the wars were ferocious (the first conflict, according to Tyrtaeus, lasted almost two decades) and bitter, the Spartans eventually emerged as the victors, and this ascendancy of their immediate neighbours led to the birth of the social class known as helots. The helots, who were all of Messenian descent, were indentured serfs (by all accounts, virtually slaves) who were bound to the land they were born on. The helots worked the fields and performed all manner of agrarian and other forms of labour, such as those of armorer or groom, requiring a high level of skill. Most importantly, this system left the Spartans truly free to follow the Lycurgan reforms and devote themselves entirely, in their every waking moment, to training and preparing for battle. According to the ancient Roman historian Plutarch, when the Spartan king Anaxandridas was asked how the Spartans dared to leave their fields in the control of the helots, he explained, "It was not by taking care of the fields, but of ourselves, that we acquired those fields."

Nevertheless, helots weren't exactly ordinary slaves. Though their status was lowly, helots were valued by many of the cannier Spartans, who saw the need to cultivate their allegiance, and helots always assisted the Spartan army in battle. Each armored heavy infantryman, or hoplite, was accompanied by a helot "squire" who also fought as a light infantryman (usually as an archer or javelineer) and helped carry his master's load, repair his *panoplia* (battle-kit) and tend his wounds.

The Spartans came to be wholly dependent on the helots in the years to come, a dependence which, as the Spartans were well aware, was dangerous.

In later years, the Spartans became so afraid of a helot revolt, something which occurred frequently enough, that they were forced to prepare a full call-up of their army only with extreme rarity, lest the helots rise up in their absence.

"At Athens, wise men propose, and fools dispose." - Alcuin

Like most cities of Ancient Greece, Athens traced its origin back to the Age of Heroes, the mythical time when gods were said to have walked the earth, mingling frequently with mortal men. Athens's foundation myth is particularly persistent, cropping up in the works of a wealth of ancient historians including Herodotus and Plutarch. It claims that the city's inhabitants, when Athens had first begun to become a significant (but still apparently nameless) *polis*, were visited by Athena, Zeus's daughter and goddess of war and wisdom, and Zeus's brother Poseidon, god of the sea and earthquakes. Both gods asked the city fathers for the honor of having the city named after them, and in order to make their offer more appealing, or so the legend goes, they both gave Athens a gift. Poseidon plunged his trident into the ground, starting a spring that would provide water for the city, while also bearing a promise that Athens would be supreme as a naval power. Athena, however, created the olive tree, the mainstay of their economy, for the Athenians, which also symbolized peace, trade and prosperity. The Athenians chose the latter, and thus named their city Athens. The olive tree which Athena had seeded supposedly grew atop the Acropolis in a sacred enclosure, where it was supposed to still be standing until it was destroyed by the Persians during the sack of Athens in the wake of the great battle at Thermopylae. Supposedly, however, a fresh shoot sprung from the burnt and broken carcass of the tree.

A replica of Phidias's statue depicting Athena

Mythology aside, archaeological evidence suggests that Athens was inhabited at the very least from the Neolithic Age, probably from between 5000-4000 BCE, making it one of the oldest known continuously inhabited cities. It is easy to see why it was such a desirable location; the rocky scarp which later became the political and religious center of Classical Athens, the Acropolis, is a fantastic natural defensive position, watered by the Eridanus river at its foot and extremely hard to climb if a determined enemy is ready to contest the heights. It also offers a 360 degree view of the flat, fertile plains surrounding it. The Cephisian plain, as it was known, was also

remarkably well-irrigated, a necessity during the baking Greek summers, and partially bordered by two mountains, Pentelicus and Himmetus. Immediately to the west, approximately three miles away, the rocky promontory of the Piraeus jutted out to sea, creating the twin bays of Piraeus and Phaleron, two natural harbors a stone's throw away which were to play a huge role in the subsequent development of Athens.

This ideal geographical situation meant that Athens prospered, quickly growing from a few scattered huts inhabiting the natural defensive position of the Acropolis into a sizeable settlement. During the Golden Age of Mycenae, Athens was one of the most prominent cities in Hellas, and there is ample archaeological evidence to support this. Though Athens somewhat surprisingly provides no great heroes to fight against Troy in Homer's *Iliad*, the remains of ancient foundations and buildings indicate that the Mycenaean era was one of undoubted boom for the city. The remains of a sizeable Mycenean fortification atop the Acropolis, dated around 1400 BCE, indicate that the city's inhabitants had, at the very least, sufficient wealth to make it worthwhile to build a fortress and curtain walls around their most important defensive outpost.

The Acropolis was also the site of a sprawling palatial complex, though little remains of it today except its foundations, and sometime around 1200 BCE the fortress was made even more formidable by the addition of a carved stone staircase, chiseled from the bare face of the Acropolis's rock, which led down to a sheltered spring, thus enabling the fortress to have its own water supply. The construction of this staircase may have had something to do with the fabled Dorian Invasion, the quasi-legendary event which, sometime around 1200 BCE, is said to have brought the Mycenean civilization low. It is unclear whether the Dorians were an invading, external force or a downtrodden majority already present on Greek soil, but their ascendancy was marked by a period of tumult and social decline for Greece, one which Athens seems to have been, by all accounts, spared. Unlike their longtime rivals the Spartans, the Athenians claimed no Doric descent, citing instead their pure Ionian lineage, suggesting that the Dorian Invasion largely passed them by, possibly because of the Acropolis's formidable natural defences. Whatever the reason, though it was spared the ravages of war Athens also seems to have suffered. Though it is unclear whether there was a particular

population drop in the wake of the Invasion, the lack of any important centers left to trade with in Greece probably took its toll, and Athens went into a decline that lasted almost two centuries.

However, archaeological evidence from Iron Age sites across Attica (Athens' heartland) seems to indicate that, by 900 BCE, Athens was one of the pre-eminent cities in all of Hellas, due to the combination of her unassailable fortified city-center and her proximity to one of Greece's best natural harbors, a double advantage which was denied to the other great *poleis*, which could usually boast one or the other (Thebes and Sparta had impregnable heartlands, while Corinth had a fine harbor). This Athenian ascendancy led to a long process of assimilation, called *synoikismos*, or "forging into one house". *Synoikismos* lasted approximately two centuries and does not seem to have been characterized by an excessive level of violence – rather, the *poleis* around Athens seem to have meekly become assimilated into the whole. By the 7th century BCE, all of Attica was under direct Athenian administration and control, creating one of the most powerful city-states in Greece.

It appears – though records are virtually nonexistent – that during this period Athens was no longer governed by Kings and had already taken the first step towards democracy by engaging in a species of oligarchy. According to tradition, the Kings of Athens, who had held sway since around 1500 BCE, ended their line with Codrus, who was said to have repelled an invasion by the Dorians around 1000 BCE, and whose descendants thereafter took on the role of Archon rather than King (though the Archonship was still hereditary for almost three centuries, its power was not as absolute as that of the Kings). The Archons were assisted in their rule by the *eupatridae* ("nobly-birthed") members, who were elected to the council of the Aeropagus, which would later become an important political organ in Classical Athens. The Aeropagus, which was named after the hill sacred to Ares, God of War, where it met, was responsible for the election of the Polemarch ("warlord") who was responsible for military matters, and a number of other minor Archons later formalized as nine.

Though a social hierarchy existed, it had not yet acquired the weight of tradition and codification, and individual political and social rights were

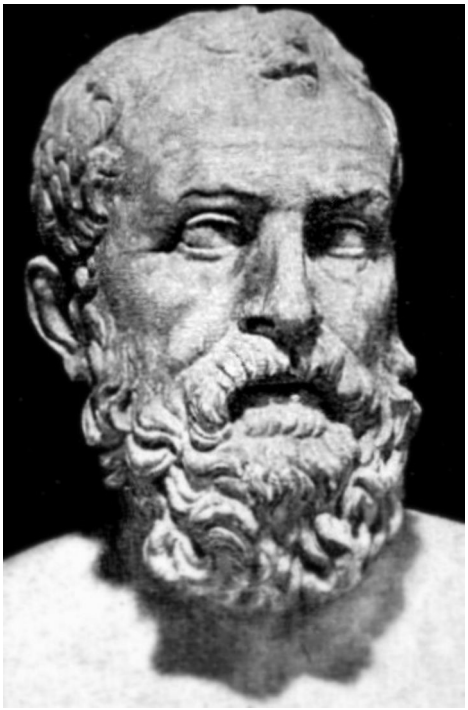
largely a question of what tribe the individual belonged to. If he was a member of one of the four main tribes whose *synoikismos* had given birth to Athens proper, then a citizen of Athens could expect a remarkable degree of freedom: he could induct (or "adopt") someone into his tribe, thereby extending those rights to him; he could worship whoever he chose; he had the right to be buried on tribal land; he could inherit his forebears' patrimony, as well as a say in the election of the Archons and other political figures; and he had the use of common tribal property. On the other hand, women had no political rights and could not inherit, nor could men marry within their own tribe unless a woman of the tribe was widowed and her family wished to preserve the dowry in her family.

The rule of the *eupatridae*, however, led to unavoidable consequences: a large, downtrodden and politically unrepresented workforce began to seethe with discontent, and by around 650 BCE matters had come to a head with social unrest rife throughout Attica. Unlike the Spartans, who chose to answer social unrest with repression, the Athenians chose a different, less-trodden path: reform. Under the auspices of Draco the Law-Giver, a new constitution was drafted and (for the first time) immortalized in writing, to prevent abuse by the keepers of the oral tradition. The Draconian code was strict – hence the adoption of the term in modern English – but largely fair: murderers were sentenced to death, those guilty of manslaughter to exile, and debtors could face slavery if their creditor was more aristocratic than they were. However, the introduction of the death penalty for a host of minor crimes proved to be politically volatile and unsuccessful.

Thus, in the wake of the Draconian reforms, which took place around 620 BCE, the great legislator Solon took over the attempts at reform in 594 BCE. All Draco's laws, save for those punishing and distinguishing homicide and manslaughter, were repealed, and the constitution was redrafted with an eye to social equality. The male population of Athens was divided into four social classes, based on wealth and taxable property represented by sacks of grain. The *pentacosiomedimnoi* could serve as *strageoi*, or generals. The *Hippeis*, or knights, could fight as cavalry soldiers (less useful in Greek warfare but traditionally more aristocratic than their infantry brethren, the hoplites). Then came the *zeugitai*, or hoplites, and the *Thetai*, or working classes, who usually carried out their military service as volunteer rowers in the fleet.

Although only *pentacosiomedimnoi* were eligible for the archonship and membership of the Aeropagus, all other citizens (including, for the first time, the *Thetai*) could sit on the *Ecclesia*, an administrative and judicial body which held the archons and the Aeropagus accountable.

Aside from sowing the seeds of Athenian democracy, Solon's reforms went a step further by helping steer Athens away from its largely subsistence-based agriculture and into the nascent commercial sector. Though economy seems to have remained barter-based until about 50 years after Solon's reforms, Solon encouraged the cultivation and export of olives, while forbidding that of other, necessary foodstuffs. Solon introduced new, standardized weights and measures, granted citizenship to skilled foreign tradesmen and craftsmen who emigrated to Athens, and finally ordered fathers to find their sons a job or risk not having the right to their sons' support in their old age. Solon also put an immediate stop to the enslavement of Athenian citizens as a consequence of debt, though foreign slaves still existed. In short, Solon had sown the seeds for Athens's future supremacy. Economic reform and a resurgent, politically involved lower class meant that Athens prospered, and though it would face more setbacks in the years to come, the course for greatness was set.



Bust of Solon

The Persian Wars and the Start of the Golden Age of Athens

Sometime between 600 and 550 BCE, Sparta was still led by two kings Agasicles and Leon, but by this point the Ephorate, a council of five elders, one from each *deme* of Sparta and with a large share of the executive power, had also been introduced. It was also around this time that Sparta waged a vicious war against the neighbouring city of Tegea, another Arcadian *polis*. Tegea resisted with unprecedented tenacity, even inflicting a serious defeat upon the Spartans at what became known as the Battle of the Fetters, and eventually Sparta was forced – in a sea-change of policy – to desist from its attempts to subjugate the Tegeans and reduce them to helot status. Sparta instead accepted a grudging agreement from the Tegeans to accept Sparta as their *hegemon* (overlord). This stubborn resistance led the Tegeans to acquire a significant amount of fame as warriors, their valour and skill at arms being characterised by ancient Greek historians as being second only to that of the Spartans themselves.

The upshot of the war was that Sparta now gained a valuable ally in ensuring the continued pacification of the restless Messenian territory, and also a buffer between its own dominions and those of the closest rival superpower, the mighty city of Argos. The following decades of Spartan policy were to be shaped by their desire to gain ascendancy over Argos, and in 546 BCE, following the Battle of Champions, Sparta inflicted another serious reversal on the Argives by taking control of the troubled no-man's-land of Cynuria. Cynuria had been a contested territory which stood between Argolis, the Argive sphere of influence, and Laconia, the fledgling Spartan Peloponnesian domain (hence the modern word "laconic", as the Spartans were notorious for being men of few words).

Approximately half a century after the Battle of Champions, in 494 BCE Sparta launched a mighty expedition under King Cleomenes with the intention of destroying Argos once and for all. The Argives fought back, but their forces were annihilated by the Spartan heavy infantry at the Battle of Sepeia, causing such devastation to the Argive war effort that they effectively became a second-rate power. The Argives were forced to acquiesce to humiliating peace terms. It is said that when Cleomenes was asked why he

had spared Argos when it lay prostrated and defenceless before him, he remarked mildly that Sparta needed the Argives – they gave young Spartans something to practice on.

The defeat of Argos established Sparta once and for all as the dominant land power throughout all of Hellas, its armies invincible and its might unquestioned. Other powers, chiefly Athens, might be more dominant at sea, but wherever battle was joined on land, the Spartans were without peer. As Sparta suddenly vaulted into ascendancy, envoys poured in from as far afield as Scythia and Lydia asking for Spartan aid against the Persian Emperor Darius, whose ruthless expansionist policy was poised to threaten half the known world, including Greece herself, for whom Sparta had taken upon itself the self-appointed role of champion.

Closer to home, the cities of the Ionian seaboard (Middle-Eastern in terms of geographic location, but Greek in ethnic background and culture) begged for help in their uprising against Darius, while the Greek cities of Megara and Plataea, and later Corinth, declared their loyalty to Sparta, establishing the beginnings of what later became known as the Peloponnesian League. The League, which would eventually become one of the great political forces in ancient Greece, did not get off to the most successful of starts. The first joint effort by the Peloponnesian League, and the first time Sparta had attempted to assert its political supremacy north of the Isthmus of Corinth, came when the two Spartan kings Cleomenes and Demaratos led an expedition into Attica, Athens's heartland. The Spartans had helped overthrow the Athenian ruler Hippias shortly before, in 510 BCE, and with two political parties, headed by Cleisthenes and Isagoras respectively, vying for supremacy, the situation seemed ripe for political exploitation. The Spartans attempted to back the conservative Isagoras, but the expedition was a complete fiasco: the allies, apprised of the Spartans' intentions, decamped *en masse*, and then the Spartan army itself was riven in two when Demaratos quarrelled with Cleomenes and decided to up the stakes and return home as well. As a result, Spartan credibility was somewhat damaged; rather than being uncontested leaders of the Peloponnesian League, they were now expected to defer to their allies when it came to decision-making, leaving them as a first among equals rather than the overlords they would have likely preferred to be. (As an interesting aside, Demaratos would later be exiled and wound up watching

the Battle of Thermopylae from Xerxes's tent.

The league itself stood firm, but its goal seems to have shifted. Rather than ensuring Spartan supremacy, it was now geared towards resisting outside intervention. Cleomenes, it appears, had scented a change in the wind. For hundreds of years, Greece had been riven with factionalism and internal strife, but the time was swiftly approaching when all such differences must be set aside. The might of the Persian empire, the greatest the world had ever seen, was being massed against them by the Emperor Darius. The Persian empire used its unimaginable wealth to equip an army whose numbers were so large they defied understanding. In fact, it's estimated that each province of Persia was capable of raising more men than all the Greek *poleis* combined.

Ancient Greek depiction of the Persian Emperor Darius

As Sparta had been establishing itself, the Athenian Solon had set the stage

for the birth of the world's first recorded democracy, but it is unclear what his motives were, or his methods. Though he allowed the *Thetai* political rights by giving them the power to sit in the *Ecclesia* and freed them from the constant fear of debt-induced bondage, Solon also switched the main agricultural production from grain to olives, and while grain was a subsistence crop it at least gave the *Thetai* something to subsist on, while olives did not (they also took several years to start bearing fruit, and those years cannot have been easy for the rural poor. It is unclear whether Solon fed them at the treasury's expense).

Sea-based trade had also been on the wane in Athens over the previous years, due to a conflict with Megara, whose ships controlled the seas around nearby Salamis and Eulesis. The Megarans were finally defeated, allowing for a much increased influx of trade, by Solon's cousin, Peisistratos in 565 BCE Peisistratos was something of a populist, and riding high on the success of his venture against the Megarans, he had ambitions of high office. However, he could not hope to achieve his political advancement based on his reputation as a *strategos* alone, so around 560 BCE he faked an attempt on his life and then went before the *Ecclesia* to demand bodyguards. Once he had the men, he used them to seize control of the Acropolis and set himself up as a *tyrannos* – a sort of benevolent dictator. Despite the fact that Peisistratos had seized power by force, he was extremely well-regarded in Athens and continued Solon's tradition by expanding Athens's trading and military influence in the Aegean, and promoting the development of schools of philosophy, science and the arts. He also realized that Athenian predominance depended on naval might, a key factor in later Athenian politics.

Peisistratos had a rocky time in office and was even exiled twice, but he managed to mostly hold onto power until his death in 527 BCE Peisistratos's title was not meant to be hereditary, but his sons Hippias and Hipparchus took power despite the wishes of most of the population, until Hipparchus was murdered in 514 BCE and Hippias set himself up as a despot. He was finally overthrown in 510 BCE, at which point government was handed to the aristocrat Cleisthenes, who in his time in office established the definitive Athenian democratic political system. He abolished the four tribes, or *philai*, whose *synoikismos* had first made Athens, and created ten non-class-based

ones, which were in turn divided into three *trittias*, each of which was responsible for one (or several) *demes*, which served as a species of neighbourhood council. Each of the *philai* provided 50 elected representatives to the *Boule*, which became the main governing body of the city. Public offices became lottery-based, save for the ten *strategoi*, where it was obviously felt that chance was a bad way of selecting a general.

Athens now emerged among the *poleis* of Hellas as a dynamic and formidable force, both politically and militarily. The Spartans, who up until that moment had been the uncontested top dog in Greece, began to sit up and take notice. In the wake of the exile of Hippias, who fled to Persia, the Spartans succeeded in establishing a pro-Spartan oligarchy in Athens, marginalizing Cleisthenes and even having him exiled, but the population of Athens rose up and expelled the pro-Spartan oligarchs, staying defiant even when the Spartans marched on Athens in what eventually turned into a military debacle for the them. It seemed as though nothing could stop the march to success of Athens and her new, radical political system.

However, barely a decade after the reforms of Cleisthenes consolidated the process of democratization set in motion by Draco and furthered by Solon, the fragile experiment of democracy risked being snuffed out altogether. Flushed with its dynamic rise to prevalence among the cities of Hellas, in 499 BCE Athens overreached itself by responding to a call for help from the *poleis* of Ionia in Asia Minor. Though middle-eastern in geographical location, the Ionians were ethnically and culturally Greek, and they were chafing under the rule of Darius of Persia. The Ionians, rebuffed by Sparta, turned to Athens for assistance in their revolt.

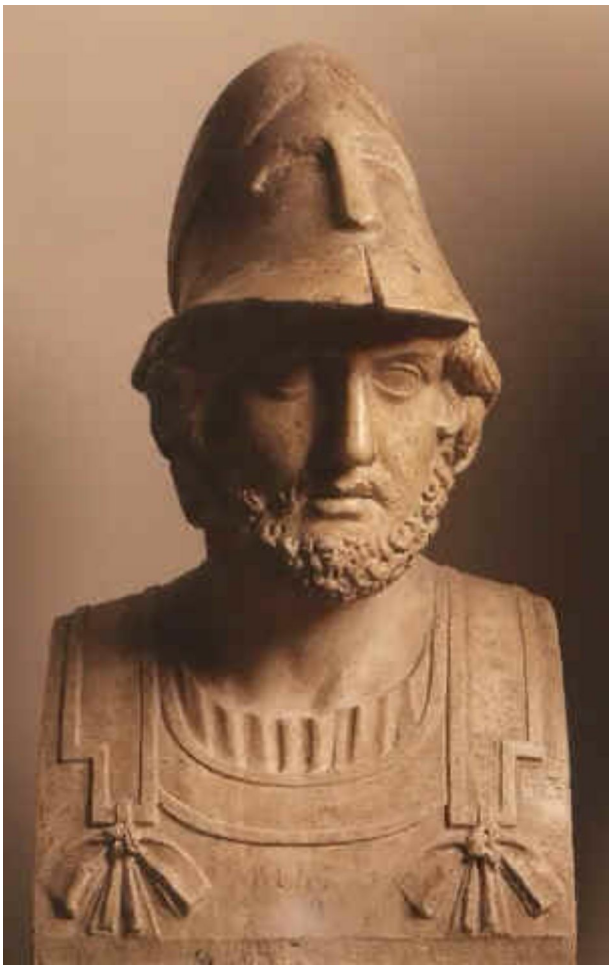
Athens had recently gone so far as to offer earth and water in submission to Persia when they had been at odds with Sparta, in return for the promise of assistance, but they eventually reversed their policy when the Persians insisted they allow Hippias to resume his place as tyrant. Thus, the Athenian fleet sailed in support of the Ionians, leading to war with Persia.

In 491 BCE, following a successful invasion of Thrace over the Hellespont, Darius sent envoys to the main Greek city-states, including Sparta and Athens, demanding tokens of earth and water as symbols of submission. Darius didn’t exactly get the answer he was looking for. According to

Herodotus in his famous *Histories*, "Xerxes however had not sent to Athens or to Sparta heralds to demand the gift of earth, and for this reason, namely because at the former time when Dareios had sent for this very purpose, the one people threw the men who made the demand into the pit and the others into a well, and bade them take from thence earth and water and bear them to the king."

Thus, in 490 BCE, after the revolt in Ionia had been crushed, Darius sent his general Mardonius, at the head of a massive fleet and invading force, to destroy the meddlesome Greeks, starting with Athens.

The Persian army, numbering anywhere between 30,000 and 300,000 men, landed on the plain at Marathon, a few dozen miles from Athens, where an Athenian army of 10,000 hoplite heavy infantry supported by 1,000 Plataeans prepared to contest their passage. The Athenians appealed to the Spartans for help, but the Spartans dithered; according to the Laws of Lycurgus, they were forbidden to march until the waxing moon was full. Accordingly, their army arrived too late. Thus, it fell upon the Athenians to shoulder the burden. With their army led by the great generals Miltiades and Themistocles, the Athenians charged the outnumbering Persians. Outmatched by the might of the heavy, bronze-armored Greek phalanx, the inferior Persian infantry was enveloped and destroyed, causing them to flee for their ships in panic. The Athenians had won a colossal victory against an overwhelming and seemingly invincible enemy.



Bust of Themistocles

According to legend, in the aftermath of Marathon one of the Greek soldiers, already battle-weary, named Pheidippides, ran the 26.2 miles back to Athens in order to announce the victory and collapsed and died as soon as he had done so, leading to the establishment of the marathon in memory of that feat in the modern Olympics. The battle has another, less inspiring aftermath, however. The year after Marathon, in 489 BCE, an expedition under Miltiades was launched against the Greek traitors at Paros. The expedition was a failure and, in what would become one of Athens's less charming traditions, the hero of the hour was turned into the villain by demagogues who realized the power of an inflamed mob in the new democratic system; Miltiades, wounded and suffering, was sentenced to death and thrown into prison, where he died of his wounds.

Despite the victory in the First Persian War, it was felt that, maybe not in

the next year or even in the next decade, the Persians would come again. The Spartan king Leonidas was the main advocate of this theory, sustaining it even when Darius died and was succeeded by his son Xerxes in 486 BCE. Under Leonidas and their other king, Agesilaus, the Spartans waged a series of campaigns in the years following the Battle of Marathon to bring reluctant allies and Persian sympathizers into the fold and ensure a united Greek front would greet all Persian attempts to invade.

That invasion, just as Leonidas had prophesied, came in 480 BCE, when Xerxes, at the head of an army which Herodotus states numbered over a million men, bridged the Hellespont (the Dardanelles straits) via a colossal pontoon bridge and marched his army into Thrace, threatening Greece proper. All eyes turned to the Spartans: the greatest warriors in all of Greece, surely, must lead the defence of Hellas. Yet once again, the Spartans dithered. It is unclear what prompted the Spartan reluctance to take the field. Some historians have suggested that, being chiefly concerned with the Peloponnese, the Spartans wanted to defend the Isthmus of Corinth, and let the rest of Greece fend for itself. Others accept the official Spartan reason that as a deeply religious people they could not ignore the Olympic proscription, in vigour at that particular time of year, that forbade Greek cities from marching in arms.

Whatever the reason, the Spartans could field only a token force: accordingly, they sent an “all-sire” suicide unit of three hundred full Spartiates, notionally the King’s bodyguard, under Leonidas, to defend the pass at Thermopylae in north-eastern Greece. These 300 were bolstered by 600 *perioikoi* or “neighbors” (literally “those nearby”), line infantry of lesser prestige from the towns surrounding Sparta, and a further 900 helot light infantrymen, one for each hoplite. They were also joined by between 3,000-5,000 thousand allied Greeks from Corinth, Arcadia, Mantinea, Tegea, Thespiae, Phokis, Locris, and others.

For three days, Leonidas, his Three Hundred, and their allies withstood wave upon wave of Persian attacks, inflicting more than 20,000 casualties upon the enemy. Finally, outflanked and exhausted, they were defeated; Leonidas sent all the allies in retreat save for the remnant of the Three Hundred, but the Thespian soldiers refused to leave, taking up their places

beside the Three Hundred. According to Herodotus, during their legendary last stand, after their weapons and armor were smashed and broken the Greeks fought on with nails and teeth before being at last cut down to the last man.

View of the pass at Thermopylae. At the time of the battle, the coastline was roughly where the road is today, and the trees on the left side of the picture would most likely have been absent.

The ideal of Spartan valor, already considered legendary, now became eternal. When the Spartans' famous and sacrificial stand at Thermopylae ended, the Athenian fleet was forced to fall back, and Xerxes's army marched unopposed into Hellas before advancing on Athens. The Greek armies were scattered and unable to face the might of Persia, so Athens was forced to do the unthinkable: evacuate the entire population of the city to Salamis, from where the Athenians watched in horror as Xerxes' troops plundered the defenceless city, set it aflame, and razed the Acropolis. However, the Athenians remained belligerent. According to the oracle at Delphi, "only the wooden wall shall save you", and this proved true when Themistocles managed to lure the Persian fleet into the straits of Salamis and there, with

the Athenians in the lead, the allied Greek navy annihilated the Persian fleet. Despite friction with the Spartans over which part of Greece should be defended, and a further evacuation of Athens, in August 479 BCE a massive allied Greek host succeeded in bringing Xerxes's general Mardonius's army to battle at Plataea, in central Greece.

The Greeks had 50,000 men, and the backbone of this force, under Pausanias, were 5,000 full Spartiates and 5,000 *perioikoi*. In the ensuing battle, the Persian forces were virtually annihilated, and though this had been a united Greek effort, the credit for the victory was placed firmly on Sparta's doorstep. Their ascendancy was further confirmed later that same year when, during the naval engagement at Mycale, the Hellenic navy (commanded by the Spartan king Leotychides) was responsible for the victory that finally scoured the Persian navy from the seas, a triumph which threatened to obscure the Athenian triumph at Salamis earlier in the war.

However, in the aftermath of Mycale, Sparta was evidently still conflicted about pursuing expansionism outside of the Peloponnese and Greece itself. Thus, they turned down overtures from the Ionian cities for help in their renewed revolt against Xerxes, rudely suggesting that they abandon their cities *en masse* and resettle in Greece, where space would be made for them by uprooting pro-Persian traitors. The Ionians, disgusted, refused to support Pausanias (now in the role of *navarch*, or admiral) in his expeditions against Byzantium and Cyprus and instead turned to Athens for help, which the seafaring power was pleased to provide. The seeds of Athenian and Spartan rivalry, seeds which would eventually blossom into the worst war in Greece's history, had been sown.

The Athenians, by contrast, were thinking bigger. Over the following decade they spearheaded a number of naval actions against Persian-held settlements and fortresses in the Aegean, further expanding Athens's influence and laying the basis for what would later become the Athenian empire. During this period the Athenian fleet, already pre-eminent, expanded and grew in experience and ability until it was the most powerful naval force in all of the Mediterranean.

It was during this period that Athens established the Delian League; initially envisioned as a league of like-minded *poleis* with Athens acting as

first among equals, but it quickly degenerated into a situation where other cities were essentially vassals of Athens. Meanwhile, the Spartans had begun to grow increasingly concerned about Athens's imperialistic ambitions and worried that their position of pre-eminence among the Greeks would soon be subverted. A crisis, it seemed, was inevitable.

Greek Architecture

Christophe Meneboeuf's picture of the Acropolis in Athens

Perhaps the most characteristic feature of ancient Greek architecture is the manner in which buildings were constructed. They were composed of upright columns supporting horizontal beams all lintels supporting a ridged roof. Originally these structures would have been composed of wood, but the great buildings people still recognize today were made of stone. The classical columns were made up of a number of stone drums which rested one upon another without mortar, though in many structures a large bronze pin ran through them. The columns tapered from bottom to top and were surmounted by capitals.

There are five orders or styles of columns based on era and place. The Doric column was fluted and is the earliest example of Greek architectural

style. The Ionic style originated in the Asian Greek colonies in the middle of the 6th century BCE and was thinner than the Dorian, with scrolled capitals and supporting ornate friezes. Corinthian columns were similar, with the capitals elaborately decorated with scrolls and acanthi. The oldest known structure in his style is the Choragic Monument of Lysicrates, a wealthy Roman citizen, constructed around 335 BCE. These four architectural styles formed the basis of Roman, and consequently European, architecture and it is difficult not to see their influence in any city or town today.

Most public buildings, particularly temples, were constructed of marble, or, where this proved impractical, of limestone with a veneer of marble dust. Marble is more malleable than many kinds of stone, and moreover, it is lightly translucent, so its beauty is enhanced in the light. Marble also assumes different colors, such as red, white, green or yellow.

City-states that used marble in constructing public buildings were displaying the wealth and grandeur of the city. Marble came to be regarded as the noblest of building materials, expressing the divine and the perfect. Even today marble is considered one of the most precious building materials, and even marble finishes are often used where real marble is not.

The Acropolis, which literally means “a city on the heights,” is a citadel whose currently surviving structures were mostly built during the 5th century BCE. in honor of Athena, the patron goddess of Athens. It functioned as a sacred precinct that contained the city’s most important religious and municipal structures, many of which have remained relatively intact for over 2,000 years. The Propylaea (the gateway to the Acropolis), the Parthenon (the principal shrine to the goddess), the Erechtheion (a shrine that supposedly houses the burial grounds of mythical Athenian kings), and the Temple of Athena Nike all survive to this day, and for these reasons, the Acropolis is perhaps the definitive and most eloquent expression of classical architecture, if not of the classical form itself.

Naturally, like many other works of its type and influence, the structures on the Acropolis embody certain traditions, but they also depart from some traditions and also transformed others. Indeed, just as the Acropolis is Athens’ most striking feature, it is also a perfect representative of the city’s golden age, both in terms of classical style and civilization as a whole. It’s no

wonder that people continue to view the Acropolis as both a portal to antiquity but also a spot with living structures whose importance continues to reverberate to this day.

The architectural complex on the Athenian Acropolis is universally acclaimed as one of the most outstanding achievements of Western Civilization, but within that group of iconic buildings there is no doubt that the Parthenon is the most famous and impressive. The Doric and Ionic forms that are the basis of classical architecture, and as applied to the Parthenon, still resonate in the modern world today, as it has done throughout the centuries since its completion. It was built to the highest possible standards at the time, and no expense was spared on either the constituent parts or its decoration.

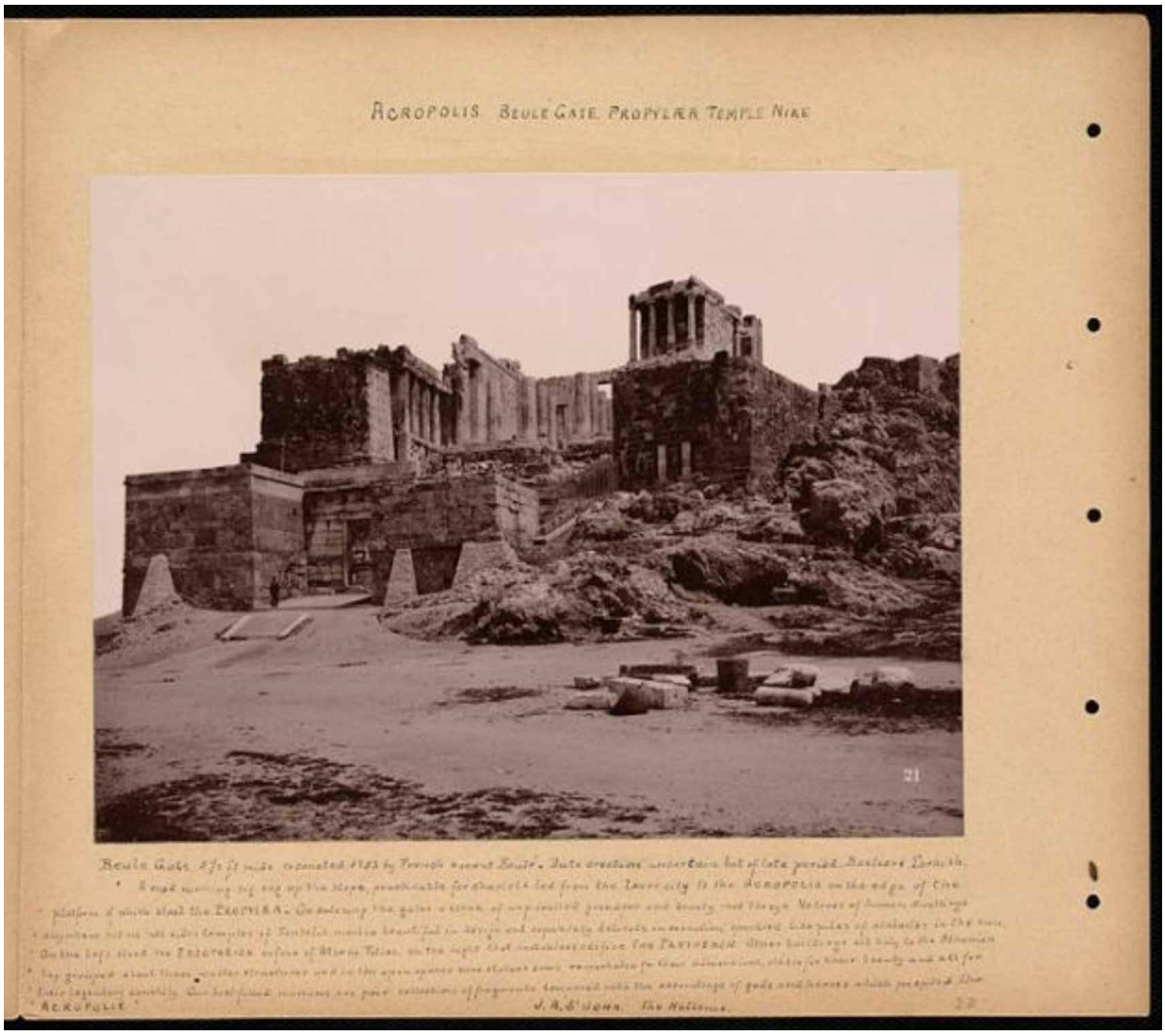
Of course, given the care and the costs, people have inevitably wondered why the Athenians put so much treasure and effort into the construction of this masterpiece, and why the temple still has such an impact on those who see it today. To fully understand this most beautiful and subtle of buildings it is necessary to contextualize its construction and its use within the Athenian religious tradition. The Parthenon has to be seen from numerous perspectives, including its historical context, its mathematical sophistication, and the myths and legends told in its sculptures and friezes. Ultimately, however, the Parthenon has to be recognised for what it was at the time, not only as a place of worship but a celebration of a momentous victory over a mighty foreign power, linked to a conscious glorification of Athens as a “cosmopolis”. There is no ambiguity; the temple was the deliberate articulation of Pericles’ vision of Athens at the height of all its glory.

Originally a walled palace, the Parthenon became a temple to the goddess of Athena, the titular god of the city. The first temple was built in the Dorian style between 550 and 570 BCE. It was torn down and rebuilt twice before being destroyed by The Persian King Xerxes in 480 BCE. The temple whose ruins stand today was built after the Persians were defeated. It housed a 9-meter high gold and ivory statue of Athena.

The present Parthenon was built in the Doric style, with 17 columns at the sides and 8 at the façade. There were 23 columns in the cella or inner temple, surrounding the statue of Athena in two tiers. Six columns marked the

entrance to the inner court. Behind the statue were the treasury and four great columns, differing from the rest in that they were in the Ionic style, whereas the others were Doric.

Leo von Klenze's painting of the Acropolis (1846)



An 1893 picture of the Acropolis showing the Beulé Gate, Propylaea, and the Temple of Athena Nike

As a piece of art, the Parthenon is superb, but it is also a technological wonder. The temple was constructed without using straight lines, and the columns narrow slightly from top to bottom and curve inwards toward the top as if they were struggling to bear the burden of the roof. There are other subtle features contained in the architecture of the Parthenon, including the fact that the architects adjusted the width of the outer corner columns in order to compensate for the brightness of light which might otherwise make them appear further apart than they actually are. Everything about the Parthenon reflects the Greeks' obsession about human artifice as the idealization of nature.

A project to restore the Parthenon to its original glory, funded by the Greek Republic and the European Union, began in 1975 and has uncovered some startling characteristics of Greek architecture. Its resilience is particularly noteworthy, considering that a great many temples and other public buildings were constructed on top of hilltops in regions noted for seismic activity. Indeed, architects and archaeologists are studying the Parthenon to learn how it has withstood multiple earthquakes during its 2,400 year history. As recently as 1999, a 5.9 Richter scale earthquake killed 143 people in the region of Athens, but it left the Parthenon almost completely intact.

The Parthenon is built on a limestone foundation 12 meters below the ground and the columns, it is to be remembered, are not bound by mortar. The blocks used in its construction were joined by H-shaped iron pins which were covered with lead so as not to corrode. However, stabilizing pins inserted in the 19th century were not so coated and had corroded by the time restoration began. It is a wonder then that a ruined temple could have withstood the rigors of an active earthquake zone, so much so that scientist and engineers from earthquake-stricken Japan have journeyed to Athens to study the building.

Initial studies have indicated that the temple’s resilience may have something to do with how the columns are constructed. Further, the fact that the Parthenon was constructed without mortar may have given the structure certain flexibility when an earthquake struck. More studies are needed, and engineering experts believe the great Parthenon has more secrets to reveal.

In its full glory, the Parthenon would have been about 45 feet high, 100 feet wide, and over 200 feet long. It took at least eight years to build, an extraordinary amount of time considering the workmanship involved and the perfection of the finished structure.

Other monuments to Greek architectural genius including the Temple of Zeus at Olympia completed in 457 BCE. Long since destroyed, it housed a statue of Zeus enthroned approximately 45 feet high and, like the statue of Athena, worked in gold and ivory. Ivory was a common material used for sculpture in the ancient world, and its combination with gold was a very popular and archaic form of statuary known as "chryselephantine" that was commonly used for oversized cult statues, perhaps because it was relatively

light compared to stone. The statue of Zeus portrayed Zeus seated on a jewel-inlaid throne, probably in a position similar to the famous statue of Abraham Lincoln in the Lincoln Memorial in Washington, D.C. It was also reported that Zeus held a small statue of Nike (the Greek goddess of Victory) in his right hand and a gold-inlaid staff, topped with a gold eagle, in his left.

A temple was constructed just to house the statue, and some reported that it was lit by fire inside the windowless temple, making the statue of Zeus a mysterious and imposing sight. To get an idea of just how large and imposing the statue itself was, the ancient historian Strabo wrote, “It seems that if Zeus were to stand up, he would unroof the temple.” It inspired awe in others who saw it as well; Plutarch wrote in his Life of Paulus that when the Roman general saw the statue, he was “was moved to his soul, as if he had seen the god in person.” 1st century BCE Greek orator Dio Chrysostom said seeing the statue could make a man forget all his troubles.

The temple, along with the statue, was destroyed by the Christian Emperor Theodosius II in 426 CE. The great statue was apparently constructed and then moved into the cella of the temple. In fact, the statue was so massive that the columns of the cella had to be dismantled to install the statue and then reassembled.

Other great architectural wonders of the Greek world include the Temple of Artemis, the Mausoleum at Halicarnassus, the Colossus of Rhodes, and the Lighthouse of Alexandria. Of the seven great wonders of the Ancient World, 5 out of 7 are products of Greek civilization.

Drawing of Colossus of Rhodes, illustrated in the Grolier Society's 1911 Book of Knowledge

The Colossus of Rhodes was a statue of Helios, god of the sun, which stood about 100 feet high at the entrance of the harbor of the island state of Rhodes. It was built by Chares of Lindos in 280 BCE as an offering for the island's victory over Cyprus. The statue was built of bronze and stood on a marble base about 50 feet high.

The Colossus took 12 years to build, and earthen ramps were raised during construction and made higher as the statue grew. The feet were carved in stone and covered in bronze plates riveted together. The ankles and legs were framed in iron and also covered in bronze plates. Most of the plates of the lower body were between 20 and 25 millimeters, while those of the upper body could be thinner, between 6.6 and 12.5 millimeters.

Little is now known about its actual appearance, such as whether it was clothed, the hairstyle, or even its posture, but it was dedicated to the sun god Helios. Some (much later) portraits of it show it holding aloft a fiery torch, much like the Statue of Liberty, indicating it may also have had a somewhat

practical purpose of guiding ships into the harbor, which had a rather narrow mouth.

This extraordinary statue, unrivaled by anything else in the ancient world, was destroyed by an earthquake in 226 BCE, 54 years after it was finished. When the Colossus was finished, it was dedicated, “To you, o Sun, the people of Dorian Rhodes set up this bronze statue reaching to Olympus, when they had pacified the waves of war and crowned their city with the spoils taken from the enemy. Not only over the seas but also on land did they kindle the lovely torch of freedom and independence. For to the descendants of Herakles belongs dominion over sea and land.”

Given its design, when the earthquake that knocked it down struck in 226 BCE, historians theorize that the plates shook loose, arms first, and the statue fell in several pieces, leaving the feet and the base standing. There is also some debate as to its position and stance. Some medieval sources claimed that it was built to straddle the harbor, as immortalized in Shakespeare's play, *Julius Caesar*. However, there are two potential problems with this image. One is a case of stability, as the bronze statue would have fallen even more quickly than it did, under its own weight. Archaeologists also believe that making the statue straddle the harbor would have required closing the entire harbor during its construction, and the destruction of the statue would have blocked entrance to the harbor as well.

More evidence suggesting the statue did not straddle the harbor comes from eyewitness accounts about the remains of the statue, such as that of historians Strabo and Pliny the Elder. Though the statue was felled by an earthquake in the early third century, pieces of it stayed where they were for eight centuries, partly because the Rhodians did not have the heart to break them down and partly because they were perhaps too large to be moved. However, they were said to be on the banks of the harbor. If the statue had straddled the harbor mouth, the falling pieces would have choked the harbor and would have needed to be moved.

After an earthquake toppled the statue and devastated the city in 226 BCE, the pieces remained for quite a long time before they were finally hauled off after the Muslim conquest of Rhodes. The 8th century CE Byzantine monk Theophanes Confessor claimed that the Muslim army sold off the pieces in

654 BCE to a "Jewish merchant of Edessa," though this story may be a literary invention intended to foretell the coming Apocalypse. It is also possible that the Knights of St. John, who held the island in the late Middle Ages, broke down the pieces and used the still-valuable bronze for scrap. At any rate, no remaining pieces have yet been discovered in modern times, so both the site and the appearance of the statue remain a mystery. Some have even speculated that it actually stood atop Rhodes' acropolis, not at the mouth of the harbor.

Though it was ultimately too experimental to have survived long, the Colossus was a remarkable achievement for the Greeks and drew much attention from Greek historians. Even those visiting after it had fallen were struck with awe at the sight of the ruins, and the ruins themselves were a tourist destination. Pliny the Elder wrote that each of the statue's fingers were larger than most statues. Not surprisingly, the Colossus has lent its name through the passage of time as a description for any large object.

The Lighthouse or Pharos of Alexandria, built on the little island of that name, was another architectural marvel. It was commissioned by the first Greek King of Egypt, Ptolemy I (r.305 – 282) and took 12 years to build. Sostratus of Cnidus may have been the architect. Fortunately, this magnificent structure survived into medieval times, and the Arab rulers of Egypt described it in some detail. It was described as being constructed of large, light-colored stone blocks and made up of three tiers. The bottom and central tower had four sides and tapered from bottom to top. It stood on a square, walled platform. A hexagonal tower stood on the first and a narrower, and a circular tower on top of that. At the apex was a flame that burned by night and a mirror that reflected the light during the day. A statue of Poseidon or perhaps Zeus surmounted the entire edifice, which stood over 600 feet tall and had a base of about 100 square feet.

The Pharos lighthouse was not the first lighthouse to be built, but it did become the model of all future lighthouses until the 18th century, so much so that Pharos became the etymological base of the word for a lighthouse in many languages. This includes the Greek word Pharos, the Persian word fanus, the Italian word faro, and the Bulgarian word far.

During the Middle Ages Lighthouse of Alexandria suffered from several

earthquakes, and the last remnants of it disappeared in 1480 when a fortress was built on the site. In 1994, archaeologists discovered remains of the lighthouse beneath the sea in Alexandria's harbor. As with the Colossus of Rhodes, a number of proposals have been put forward to reconstruct the Lighthouse of Alexandria, but to date, no efforts have been made.

Engineering

Given that the Greeks built architectural wonders, it's no surprise that their engineering was advanced for the era.

At first, the Greeks used the simple technology of ramps to move stone and other materials vertically. However, around 515 BCE, there is evidence that machines were used for this purpose.

The invention of the winch and pulley led to the use of cranes. The simplest crane was called the trispastos, which operated by three pulleys and had a 150 kilogram load. The crane had certain advantages over a ramp, especially for a polis, since it required few men to operate it, whereas a ramp required many slaves to haul material in place. Small city-states did not normally have the ability to mobilize such a workforce.

Over time, the manner of construction accordingly changed. Blocks tended to be smaller and columns were constructed of smaller and more manageable pieces rather than a monolith. Cranes were later devised for handling heavy loads, which were moved by men walking on a treadmill. In fact, a variety of cranes were constructed for different needs, and they could be moved by animals or by men usually on wheels. The four-mast crane was constructed of four vertical joists connected to horizontal beams and was moved on rollers to where it was needed. Another variety of crane had winches on either side of a vertical frame. The lifting arm could be rotated on its base, which made it suitable for loading and unloading ships and for the construction of ports.

Other lifting mechanisms used by the Greeks included the hoist, which used a pulley with up to 4 reels. They also devised a variety of ingenious ways of mooring rope in stone blocks for the purposes of lifting them. Two horizontal grooves might be carved into the bottom to allow a doubled rope to be attached to a hook. Four equidistant holes might also be bored from top to bottom and the doubled rope threaded through them. Another method

entailed carving four vertical grooves along the sides of the stone. The Greeks devised a variety of bronze-articulated tongs or pincers that clung into carved grooves. Metal wedges in trapezoid sockets were also used to great effect.

As admirable as these inventions were, the Greek use of hydraulic power is perhaps the most impressive in the minds of modern engineers. The kilonion, a relatively simple device consisting of a horizontal beam with a bucket on one side and a counterweight on the other, drew water from rivers, streams, and wells and was used by other ancient civilizations. In ancient Greece, this technology developed into the hydraulic wheel, the first evidence of which is to be found at the excavations of Perachora Korinthias, which was a sanctuary in honor of the goddess Hera ruled by the polis of Corinth. Ruins here from the 3rd millennium BCE indicate the presence of this ancient water pump, which consisted of a large wheel moved by animals, such as an ox, rotating a small prolonged wheel, which in turn rotated another wheel that turned the larger one. Water was drawn in bronze or clay buckets and tipped into a channel. Such a pump was used for irrigation purposes.

The 4th century BCE Athenian architect Philon designed a water pump consisting of a large radiated wheel positioned over a channel. A man striding on top drove the wheel, and embedded wooden containers emptied water into wooden channels. The same architect also invented the mangani, a vertical chain of container suspended above a channel. It emptied water into an elevated wooden channel and, unlike the previous pumps, was driven entirely by the force of the water itself.

The most famous ancient Greek pump is undoubtedly the Archimedes screw or screw pump. At its heart, the screw is a fairly basic design, but it is an elegant solution to a long-lasting problem: the need to transfer water from above its level. The ancient world had devised a series of solutions to this problem, from the construction of aqueducts to the employment of bucket and pulley systems and water wheels, but aqueducts still flowed at least slightly downhill and other systems had a limited capacity. Archimedes sought to remedy this problem with the construction of the Screw. The mechanism was a giant cylindrical screw, fashioned in much the same shape as a common wood screw, sheathed within a cylindrical receptacle. The

screw apparatus, which would either have been constructed of wood or of sheet metal, was turned depending on size by either a man using a lever or draught animals such as horses or oxen. The bottom end of the screw would be placed in the water, while the top end would be the height to which the water should be displaced to. The action of turning the screw would slowly move the water vertically, and while some water might escape because the seal between the edge of the screw's "blades" and the cylinder containing it could not be watertight (since otherwise the screw would not turn), the seepage was slight.

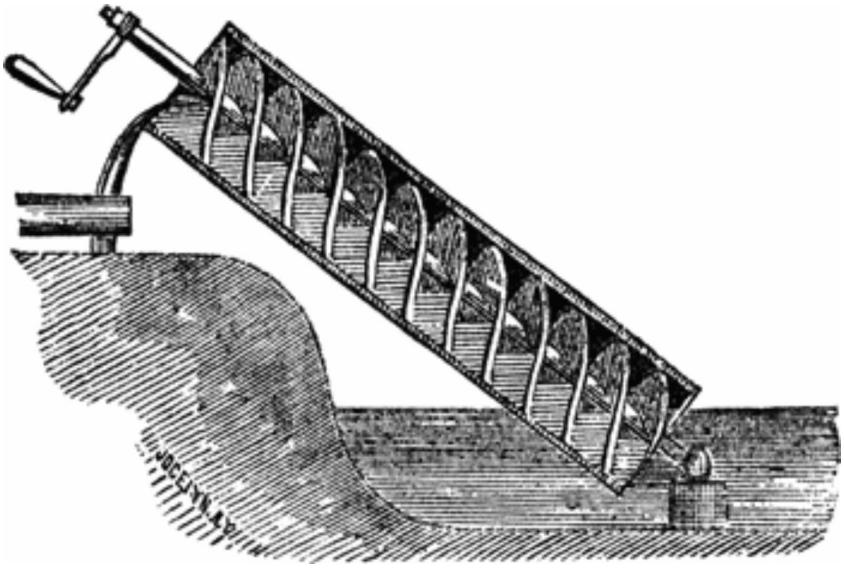


Illustration showing the function of the screw

Some researchers have suggested that the ancient Greeks were not the first to use such a pump. For example, the archaeologist Stephanie Daly has suggested that the Assyrians used it in the construction of the Hanging Gardens of Babylon. However, even if this is the case, it appears that it was the Greeks who designed a device that could be widely disseminated.

The Greeks applied hydraulic technology to other purposes besides irrigation. Hero of Alexandria (c.10 – c.70 AD) was a philosopher, mathematician, and engineer who invented a great many devices, and he seemed to have been fascinated with water and its possibilities in engineering. He constructed a twin suction force piston pump with a pivoted lever. The tank moved on four wheels and was used to combat fires. The same genius who invented this contraption also designed an area pump

consisting of a waterproof metal ball with a piston inside that compressed air, causing water to spray out through a nozzle. It is easy to see how this device might also be useful in firefighting.

While not an engineering device, the Pythagoras cup is also worthy of mention. This unusual drinking vessel is considered to be an invention of the 6th century BCE philosopher Pythagoras, who purportedly used it to demonstrate the virtues of moderation to his disciples. The metal cup had a siphon in the center of it, and when it was filled above the level of the siphon all of the liquid was drained through that siphon. The Pythagoras cup was also called the cup of justice because it illustrated the effects of vengeance: punishment commensurate to the offense was justice. To the Greeks, excessive punishment was not only unfair but emptied the action of justice entirely. Cisterns in modern toilets operate upon the same principle as the Pythagoras cup - when the water level reaches the top of the siphon the contents of the cistern drain away.

Military Technology

The ancient Greek poleis were built on natural defenses, such as hilltops or by rivers or circumscribed by sea. Moreover, they were invariably defended by city walls. The earliest fortification would have been wooden palisades such as those mentioned by Homer in the 8th century BCE, and the English word wall comes (through Latin) from the Greek word for “stake” or “post.”

Several centuries later, the Greeks were building complex defensive walls made of stone. The most famous of these walls were those of Athens, begun after the Persians sacked Athens in 480 BCE. When rebuilding the wall, the Athenians were conscious that their main strength lay in its military and mercantile fleet. Thus, not only did they build walls around the city and around their port, Piraeus, but they constructed a fortified thoroughfare between the two settlements, over a distance of 6 kilometers. This Long Wall made Athens nearly impossible to conquer because, until the 4th century BCE, cities in ancient Greek times were mostly taken by starving the inhabitants and forcing them to surrender. Greek armies did possess and use siege engines, as will be described below, but these rarely took cities by themselves. The Long Wall prevented an army from surrounding Athens and cutting its supplies, and Piraeus could not be effectively blockaded on

account of the size and strength of the Athenian fleet. In the 440s the Athenians added a second wall connecting the city and the port, at a time when their naval power was declining.

Siege technology was important in the endless wars between the Greek city-states. However, until the 5th century, the ancient Greeks rarely engaged in the full-scale city assaults, preferring to rely on the prowess of their soldiers in pitched battles or skirmishes. The reliance on sieges changed in 399 BCE when the Carthaginian general Himilco laid siege to the Greek city of Syracuse in Sicily. The Carthaginians surrounded the city and its 30,000 defenders with 50,000 men. The King of Syracuse, Dionysius, had made extensive preparations for the siege, refortifying the wall that surrounded not only the isthmus upon which the original city was built but the suburbs on the mainland as well. He also built a seawall around a section of the harbor in order to protect his fleet. These systematized fortifications defeated the Carthaginian enemies.

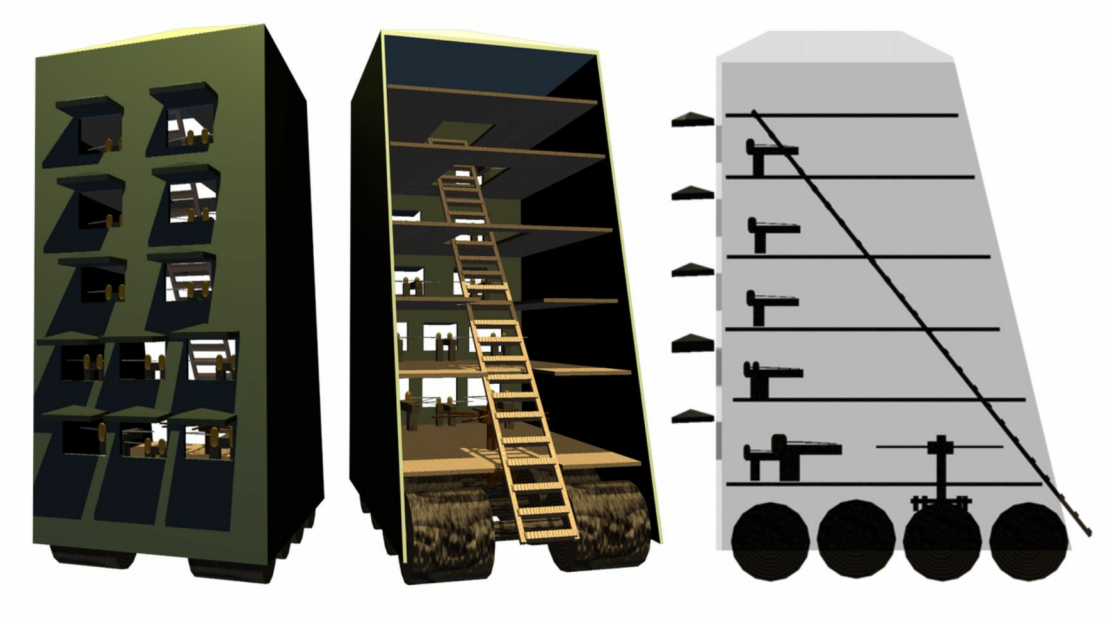
Just decades after the Siege of Syracuse, the Greeks were devising a variety of war engines for both defensive and offensive purposes. The hovering ram was one of the first weapons designed for directly assaulting the walls of a city. It was relatively simple in construction, consisting of a metal-capped beam suspended in a frame that was drawn on wheels. The suspension allowed the beam to be thrust against a stone structure at different angles, the better to exploit weaknesses. The advantage of this machine was that it was relatively light and easy to move. On the other hand, however, it was unprotected from missile attacks and incendiary weapons such as burning pitch.

In the 4th century BCE Alexander the Great’s engineer, Diades of Pella (nicknamed “The Besieger” on account of his prowess in designing siege machines), made a mobile ram that was completely enclosed in a tent-shaped wooden casing with a fire-proof pitched roof. At the front of the engine was a three-story turret with windows in which were placed archers and small catapults. The heavy ram was moved over cylindrical rollers and thrust by means of ropes. Water was even stored within the engine to put out fires that might break out. The trypanon or “borer,” also invented by Diades, was a modification, with no turret and a ram moved by a winch and pulleys. Unlike

a standard ram that attempted to shatter stone, the trypanon had a pointed tip for penetrating walls.

Another device utilized by Diades was the tortoise, a wheeled cage with four padded walls forming a pyramid. This contraption was moved to defensive ditches, where engineers within it filled them in to allow siege engines such as rams to approach the enemy's walls. The tortoise's protection consisted of steel plates, wickerwork, clay mixed with hair, and lambskins filled with vinegar-soaked seaweed.

The work of the tortoise might very well have preceded the coming of the helepolis, a formidable engine invented by Epimachos for the Siege of Rhodes in 305 BCE. The name helepolis means "city taker," and it was a siege tower 9 stories (41 meters) high. According to Diodorus, it was a siege tower with a square base of 50x50 cubits (about 75x75 feet), and it stood a total of 9 stories high. The machine was framed from timber and iron, and was mounted on 8 solid wheels covered in iron plates. Plates of iron also covered 3 of the 4 walls of the device. Every story was filled with a wide array of engines to launch projectiles, and long beams protruded from the sides. The wheels were fixed on pivots to allow for greater facility of movement, and the device was pushed both by men inside the machine and behind it, with a total of 3,400 men required to move it. Demetrius the Besieger, whose forces were the ones laying siege to Rhodes, also constructed more penthouses to protect his siege engineers, and the various other siege engines he already had at his disposal. In preparation for the attack, Demetrius also had the land in front of the Rhodian walls cleared (Diodorus Siculus, XX, 91).



Evan Mason's diagram of the Helepolis

Demetrius was unsuccessful in his ambition to capture Rhodes, despite the helepolis. After the siege, it was dismantled by the Rhodesians and its plate was melted down to contribute to the construction of the famous Colossus. The Assyrians had used siege towers before the Greeks but the helepolis was the largest and most formidable of its day, and the inspiration for the great siege towers of the Romans.

The Sambuca was an armored siege ladder which transferred soldiers to the enemy's wall. The ladder balanced on a pyramid-shaped mount by means of a pivot and was weighted by a box of lead at one end. The other end supported an assault platform with a door that was pulled up with ropes. The mount moved on wheels, and inside men turned a giant screw that moved the ladder to the required position. The ladder itself was enclosed and protected by wicker and materials similar to those that protected other engines such as the tortoise and helepolis.

The ancient Greeks also developed a variety of ballistic engines that could assail city walls, such as an arrow-firing catapult used in the Siege of Motyla in 397 BCE. This engine appears to have been modeled on the crossbow or gastraphetes, a much earlier invention of the Greeks from the 5th century. The gastraphetes or "belly-releaser" was mounted on a stock and cocked by resting it on the ground with a cavity at the end of the stock pressing into the

stomach.

The oxybeles used at Motyla were soon supplanted by larger and more powerful catapults, such as the engine invented by Zopyrus of Tarentum in the 5th century, which could fire 2 heavy bolts and was cocked by a windlass. The catapult of Isidoros of Abydos was over 12 feet long and could fire stone balls weighing up to 40 pounds.

The palintonos of Diades was the great howitzer of its day, standing about 20 feet tall and hurling massive projectiles. The central beam was cocked by a powerful winch and held in place by ratchets. The massive arms that held the string were supported by an ingenious pair of torsion springs. The monagon employed by the Macedonian army also hurled large stones, but by a joist supported by a torsion spring. It was cocked by a rope wound around an axle turned by handspikes.

The ancient Greeks did not invent Greek fire, the mysterious liquid fire used by the Byzantines that burned on water, but they did use incendiary weapons. Pitch, oil, resin, sulfur, quicklime and animal fat were all used, not only by the Greeks but by many ancient armies. However, the Greeks applied engineering technology to their use in siege warfare. In the Peloponnesian War (431-404 BCE), which the Spartans fought against Athens and its allies, the Boeotian League employed an ingenious engine consisting of a hollowed out beam, bound in iron, mounted on a four-wheeled carriage. At the rear end of the beam was a giant bellows while a metal bucket was suspended at the front. This bucket or cauldron contained a mixture of burning coal, pitch, and sulfur, kept constantly aflame by the bellows blowing air through a metal that curved into it. When the bellows was worked hard great flames were created that burned wooden walls and their defenders. This terrible flamethrower was also modified to crack stone by the addition of substances such as urine and vinegar.

The most extraordinary weapon in Greek history was probably an invention of Archimedes, for this giant of Greek mathematics and engineering built a working cannon 1,500 years before they were first employed in European warfare. It consisted of a metal cylinder encased in a wooden barrel, supported by a tripod: 2 spiked legs elevating it midway down the barrel and another pole protruding from the rear. The top of the barrel was blocked by a

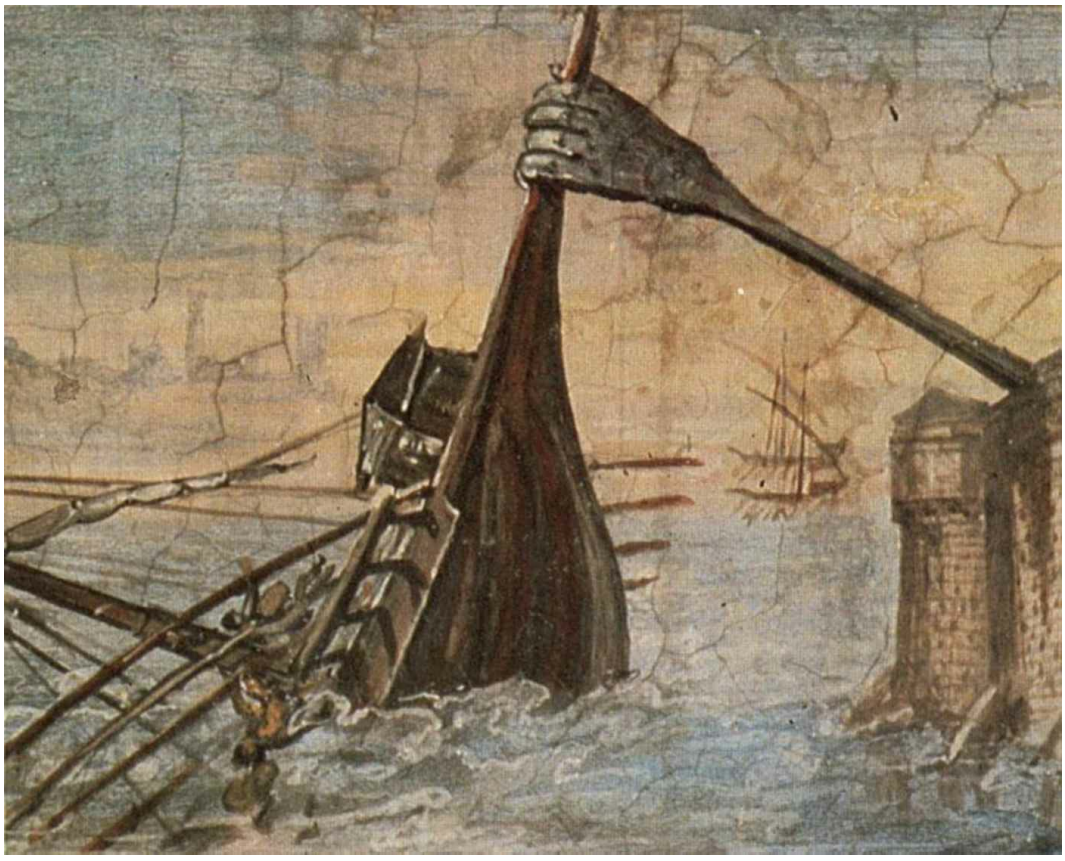
wooden joist. The bottom end of the barrel was an empty chamber heated by a fire underneath. When the air in the chamber reached a certain temperature, the valve containing water opened and emptied itself into the chamber. The water would instantly evaporate and fire a stone ball resting in the metal cylinder.

Leonardo da Vinci recreated this weapon in the late 15th century, attributing it to Archimedes and called it the Archinoterre. The cannonball apparently weighed nearly 70 pounds, and modern reconstructions of the cannon have demonstrated that it had a range of up to 1,250 feet. When the Industrial Revolution came, several attempts were made to produce a cannon fired by steam, and all of them were unsuccessful. In fact, it was not until the Second World War that the Holman manufacturing company made a steam operated weapon in the United Kingdom, an anti-aircraft gun. Even then, it could only target low-flying aircraft at about 300 feet.

Another mysterious invention attributed to Archimedes is variously referred to in ancient sources with such grandiose names as “The Ship-Shaker,” “The Snatcher,” and the “Iron Hand,” but today it is best known as Archimedes Claw. Whatever it looked like, it was a unique weapon that was never subsequently replicated by any other civilization, including the Romans. That has led many to doubt its very existence, but the ancient historians described it in particular detail. For example, Polybius wrote, “Other machines invented by Archimedes were directed against the assault parties as they advanced under the shelter of screens which protected them against the missiles shot through the walls. Against these attackers the machines could discharge stones heavy enough to drive back the marines from the bows of the ships; at the same time a grappling-iron attached to a chain would be let down, and with this the man controlling the beam would clutch at the ship. As soon as the prow was securely gripped, the lever of the machine inside the wall would be pressed down. When the operator had lifted up the ship's prow in this way and made her stand on her stern, he made fast the lower parts of the machine, so that they would not move, and finally by means of a rope and pulley suddenly slackened the grappling-iron and the chain. The result was that some of the vessels heeled over and fell on the sides, and others capsized, while the majority when their bows were let fall from a height plunged under water and filled, and thus threw all into confusion. Marcellus'

operations were thus completely frustrated by these inventions of Archimedes, and when he saw that the garrison not only repulsed his attacks with heavy losses but also laughed at his efforts, he took his defeat hard. At the same time he could not refrain from making a joke against himself when he said: 'Archimedes uses my ships to ladle sea-water into his wine-cups, but my sambuca band have been whipped out of the wine-party as intruders!' So ended the efforts to capture Syracuse from the sea."

Similarly, Plutarch described the effects of the Claw: "At the same time huge beams were run out from the walls so as to project over the Roman ships: some of them were then sunk by great weights dropped from above, while others were seized at the bows by iron claws or by beaks like those of cranes, hauled into the air by means of counterweights until they stood upright upon their sterns, and then allowed to plunge to the bottom, or else they were spun round by means of windlasses situated inside the city and dashed against the steep cliffs and rocks which jutted out under the walls, with great loss of life to the crews. Often there would be seen the terrifying spectacle of a ship being lifted clean out of the water into the air and whirled about as it hung there, until every man had been shaken out of the hull and thrown in different direction, after which it would be dashed down empty upon the walls."



Giulio Parigi's painting of the Claw

Experimental archaeologists have always been fascinated by the idea of the Archimedes Claw. They have been able to recreate modern reproductions of the Claw that worked, based upon scientific estimates of the technology that was available to Archimedes. According to the ancient sources and demonstrations of workable reproductions, the Claw was developed by Archimedes during the siege of Syracuse specifically to counter the threat of a Roman naval assault. In essence, the Claw operated like a vast crane, either employing a colossal counterweight or teams of men and oxen to haul on a cable. This cable (in all likelihood an anchor cable from one of the Syracusan quinquiremes, possibly made of Nile papyrus, an incredibly resilient material) was threaded through a crane arm and was tipped by a huge iron grapnel, shaped like a claw.

It is unclear whether the claw was hinged and thus designed to grasp, much like a modern crane's grapnel, or whether it was merely a barbed lump of iron, but in either case, its purpose was clear. The Snatcher was mounted on

the ramparts overlooking the harbour with its arm extending over the waters of the narrow bottleneck that gave access to Syracuse’s protected docks. Once an enemy ship sailed within range beneath it, the Claw would be dropped onto its decks, at which point one of several outcomes could be expected. The Claw might smash through the tender midsection of the ship, creating a hole below the waterline that would help sink it once the Claw was withdrawn. Otherwise, the Claw would tangle with the ship’s rigging, during which the defenders would start using counterweights that would literally lift the ship out of the water several feet in the air, possibly shake it, and then drop it back into the sea. This massive shock would either pull apart the individual planks which made up the ship’s hull, letting in a flood of seawater, or tip the ship onto its side, causing it to rapidly sink.

However he designed it (assuming he did), the Claw proved to be a devastatingly effective weapon, so much so that despite a significant numerical superiority, the Roman navy was never able to breach the Syracusan harbour despite blockading it for over two years. Polybius also described a similar machine Archimedes apparently concocted to deal with Roman infantry too: “At the same time Appius Claudius Pulcher found himself faced with similar difficulties when he attacked by land, and finally he abandoned the attempt. While his troops were still at a distance from the walls they suffered many casualties from the mangonels and catapults. This artillery was extraordinarily effective both in the volume of its fire, as was to be expected when Hiero had provided the supplies, and Archimedes designed the various engines. Then, even when the soldiers did get close to the wall, they were so harassed by the volleys of arrows and darts which continually poured through the embrasures, as I described above, that their advance was effectually halted. Alternatively, if they attacked under cover of their penthouses, they were crushed by the stones and beams that were dropped on their heads. The defenders also killed many men by means of the iron grappling-hooks let down from cranes, which I mentioned earlier: these were used to lift up men, armour and all, and then allow them to drop. In the end Pulcher withdrew to his camp and summoned a council of the military tribunes, at which it was unanimously decided to use any other methods rather than persist in the attempt to capture Syracuse by storm. And this resolution was never reversed, for during the eight months' siege of the city

which followed, although they left no stratagem or daring attempt untried, they never again ventured to mount a general assault. So true it is that the genius of one man can become an immense, almost a miraculous asset, if it is properly applied to certain problems. In this instance, at any rate, the Romans, having brought up such numerous forces both by sea and by land, had every hope of capturing the city immediately, if only one old man out of all the Syracusans could have been removed; but so long as he was present they did not dare even to attempt an attack by any method which made it possible for Archimedes to oppose them."

Despite its revolutionary nature, the Claw was a fairly basic mechanical device, but some of Archimedes' other designs were so remarkable that to this day the debate continues as to whether they ever existed at all. Archimedes' use of mirrors is probably the most contentious of his "inventions".

The use of mirrors is first mentioned by Lucian, who wrote about the siege of Syracuse more than three centuries later, and it was subsequently mentioned as late as the mid-400s AD by Anthemius, a Greek scholar who published a study entitled *On Burning Glasses*. Cassius Dio, another Greek historian who lived during the early 3rd century A.D., also may have mentioned it in passing. An edited version of Cassius Dio's history (edited by a medieval writer named Zonaras) stated, "Marcellus crossed into Sicily and proceeded to besiege Syracuse. The city had submitted to him, but then had revolted again as the result of a false message sent by the treachery of certain men. Now he would have subdued it very speedily, as the result of a joint assault upon the wall by land and sea, had not Archimedes with his inventions enabled the inhabitants to resist for a very long time. For this man by his devices suspended stones and heavy-armed soldiers in the air, and these he would let down suddenly, and presently draw them up again. And he would lift up ships, even those equipped with towers, by means of other appliances which he dropped upon them; and raising them aloft, would let them drop suddenly, so that when they fell into the water they were sunk by the impact. At last in an incredible manner he burned up the whole Roman fleet. For by tilting a kind of mirror toward the sun he concentrated the sun's beam upon it; and owing to the thickness and smoothness of the mirror he ignited the air from this beam and kindled a great flame, the whole of which

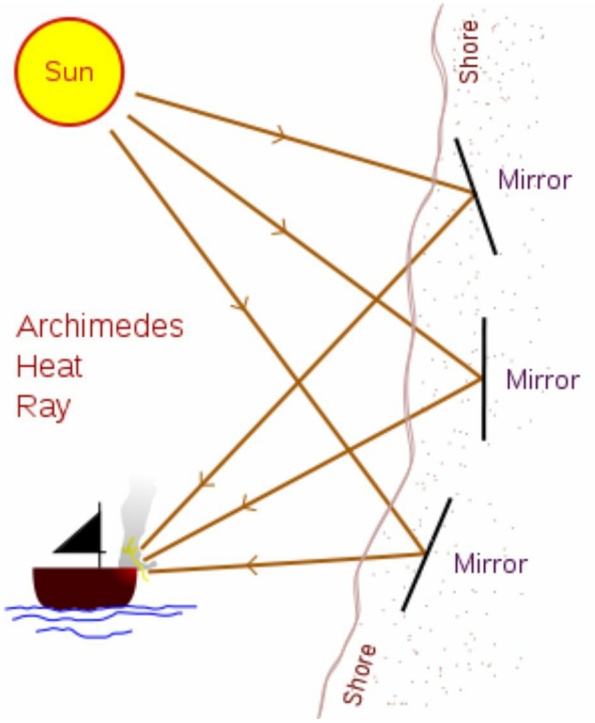
he directed upon the ships that lay at anchor in the path of the fire, until he consumed them all."

A medieval Byzantine writer named Tzetzes wrote about the mirrors even more descriptively nearly 1500 years after they were allegedly used: "Archimedes constructed a kind of hexagonal mirror, and at an interval proportionate to the size of the mirror, he set similar small mirrors with four edges, moving by links and by a kind of hinge, and made the glass the centre of the sun's beams … So after that, when the beams were reflected into this, a terrible kindling of flame arose upon the ships, and he reduced them to ashes a bow-shot off."

According to Lucian and Anthemius, during the siege of Syracuse, Archimedes devised a heat-ray that could literally set Roman ships on fire from a significant distance. Although many have been skeptical of these assertions throughout history, several recent experiments (including most recently on *Mythbusters*) have met with a varying degree of success in recreating a "heat ray" utilizing materials that would have been available to Archimedes. The sources theorized that Archimedes' Mirror was a series of mirrors made out of hammered silver or bronze polished to a high sheen and placed upon the battlements on a rotating base. If the rays of these mirrors, once they reflected the sun, were aimed in a concentrated fashion at precisely the right angle, these could theoretically have generated enough heat to reach over 570° Fahrenheit, hot enough to ignite the wooden Roman ships.

The idea of a "heat ray" has captured the imagination of people for thousands of years, and Rene Descartes himself considered the possibility of the heat ray before finding it implausible. One modern test upon timber which had been liberally treated with flammable pitch (as Roman ships would have been, since it was used in caulking and absorbed by the wood) resulted in the timber igniting. Other tests were less successful and merely produced a minimal, localized amount of charring, though it could be argued that even a small amount of fire and flames could quickly spiral out of control on an ancient war-galley, where virtually every item on board was highly flammable. Moreover, to people unaware of the science behind the phenomenon, the sight of their ships' timbers suddenly igniting for no conceivable reason was liable to be a terrifying experience.

With that said, it seems unlikely that Archimedes devised a heat ray. The more contemporary ancient sources meticulously described the siege weapons and defenses, but they said nothing about using mirrors. Even if the mirrors did work, it's unclear why mirrors would be used instead of the more conventional methods of setting fire to enemy ships with the use of fire arrows and burning artillery, which would be both easier to use and more effective. Given that, it would make more sense to assume that if the mirrors were used, they were used to blind and disorient the Roman sailors, not to burn the ships. If the men steering the ships became disoriented, they might run afoul of a reef or not see sunken obstacles, thereby endangering the attacking boats. They might even collide with each other.



A conceptual design of the mirrors

The popular television science show Mythbusters attempted to burn a wooden ship using an array of mirrors. The show's experts concluded that an impractically large lens would be required to raise the temperature of a wooden warship by just a few degrees and certainly would not ignite it. They determined that the ignition temperature of the wood was 300 degrees Celsius. On the other hand, a Greek scientist named Ioannis Sakkas successfully concluded an experiment in 1973 whereby 70 copper-backed

mirrors with a volume of about 3x3 feet caused a mock plywood Roman galley to burst into flames from a distance of 150 feet. The ship was coated in tar, which aided the inflammation, and indeed, a ship of the time would have been constructed with tar.

The Massachusetts Institute of Technology carried out a similar experiment in 2005, this time with 127 30-centimeter-high mirrors. These caused flames to break out on a portion of the ship, but only after it had been stationary for 10 minutes.

A balanced judgment would seem to be that Archimedes' feat would have been theoretically possible, but it would have depended on some unreliable factors. The sky would have had to remain cloudless. Moreover, the ships would have had to have been attacked at the optimal time of day and remain stationary for a considerable period of time. The truth of the matter may be that the destruction of the Roman fleet was caused primarily by flaming missiles, while mirrors played a small part. It might be safely concluded that the attempt to construct weapons with mirrors, if it did occur, was not entirely successful, for if it had such weapons would have been regularly employed.

Religion, Culture, and Entertainment

Given the importance of religion to the Greeks, it's no surprise that they employed technology at various temples and cults.

The Greeks became experts in using air compression and steam in their technologies. Heron of Alexandria experimented with automation, one of his first inventions being a set of automatic doors. A chamber of air was concealed beneath the altar fire in a temple. The heat from the fire would expand the air in the chamber, forcing water to siphon off and exert weight on ropes that would open the temple doors. He also invented another device of convenience for the temple which dispensed holy water to worshippers. A coin was inserted into a slot which, much like a vending machine today, produced a small amount of the sacred liquid. The coin would fall onto a pan, which when pressed would cause a lever to open the valve, allowing water to escape. The pan would continue to tilt downwards until the coin slid off. Thus, the lever would shut the valve and return to its original position.

Heron also applied his ordinary talents to the theater. His automatic theater

is surely one of the greatest achievements of his or any other age. It consisted of a stage mounted on a high pillar. The stage was fronted with a double door which opened automatically. There were no human actors on stage - scenes and figures were being painted on parchment and moved on rolls. Cut-out figures were moved along slots on the stage and sound effects were produced by falling weights. Little oil lamps could even be lit to produce light effects. The truly extraordinary aspect of this ancient cinema is that it operated almost entirely without human intervention. In fact, the only thing a human had to do was pull a string once, thereby initiating the movement of weights, pulleys, and wheels to tell a perfectly synchronized visual story.

The automated theater of Philon told the story of the mythical mariner Nauplius, who seeks revenge upon the Greeks returning by sea from Troy since they killed his son Palamedes during the Trojan War. In this “play,” figures such as men sawing wood, dolphins frolicking and the goddess Athena move mechanically, and sound effects for lightning were created.

Another automation created by Heron depicted the god Dionysius being honored by dancing worshippers. Statuettes of the god and his followers stood on a disc supported by 4 columns, which were in turn mounted on a square carriage. The carriage moved into position on castors and the show began. A lamp of oil ignited a small altar, whereupon water would exude from the tip of the god’s staff, an allusion to the honey which was supposed to drip from his staff. Then the dancing figures would move around the figure of Dionysius to the sound of small hammers representing music. Finally, the god himself would turn on his base, and the entire edifice would move back to its original position. As with Heron’s automated theater, it required only the pulling of a string to set it in in motion. The extraordinary feat was accomplished by tens of feet of thread which formed the machine’s program. They were set in motion by the slow sinking of a lead weight into a tube of millet.

The application of theatrical technology was not applied solely to novelties such as automatic displays. Such devices as the trap door, moving scenery, and hidden passages, mainstays of modern theaters, might not seem particularly impressive as evidence of the Greek genius. However, others such as the deus ex machina would surely inspire wonder even in present-day

audiences. The deus ex machina (“a god from the machine,’ a Latin phrase) was a mounted beam with a harness at one end and a pulley on the other. It could be rotated, raised and lowered, and was used to create the allusion of heroes or gods descending from the heavens. The crane might be 60 feet or more in length. There are a number of examples of it being used in classical theater, one of the most cited being related to *Medea*, a play of Euripides. In Medea, the sun god Helios suddenly descends in a dragon-drawn chariot and whisks his granddaughter, Medea, away from her husband Jason. The wonder created by the sudden appearance of such divine visions gave rise to the literary expression deus ex machina, meaning an unexpected and miraculous device used to resolve a plot.

Other theatrical constructions included the periaktoi, three-sided prisms rotating on a central pole with scenery painted on the sides. They formed the set on either side of a central door where the actors entered and exited. For a rapid change of scenery, they were simply rotated to the required setting. Also worthy of mention is the exostra, the precursor of the rotating stage. It was a low semi-circular platform with steps borne on wheels, used to bring actors or objects on or off-stage.

Philon’s expertise led him to design the first robot, a machine that simulated a human being. His automatic servant was made in the semblance of a female and served wine and water to guests. There were two containers within the chest of the automaton, one holding wine and the other holding water. A pipe from each container leads off into a jug held in the servant’s right hand. When a cup was placed in the palm of the left hand, the arm lowers, causing a mechanism to pump water wine into the cup. The weight of the wine in the cup caused the hand to lower further, triggering the addition of water through its own tube. The further weight of the water shut up off the supply of wine. The water would flow alone for a few moments and then be shut off as well.

Such automatons as the serving girl were not, apparently, considered uncommon wonders in the ancient world. The Antikythera Mechanism is the only such complex mechanism that survives in some form to this day.

Discovering ancient shipwrecks hasn’t been a novelty for thousands of years, but when artifacts were salvaged from a Roman shipwreck off the

Greek island of Antikythera in 1900, the discovery of one set off one of the great mysteries of antiquity. When sponge divers investigated the shipwreck, they found the kind of items often associated with such discoveries, including marble statues, pottery, jewelry, and coins, but they also discovered a strange object, the likes of which nobody had ever seen before. Initially assumed to be pieces of rock, it turned out that the item, soon to be dubbed the Antikythera mechanism, consisted of dozens of pieces, many of which had gears. In fact, while scholars quickly deduced that it had an astronomical purpose, many believed the mechanism was too advanced to actually date back to antiquity.

As it turned out, of course, the Antikythera mechanism did date back to the 1st or 2nd century BCE, and as scholars began to more fully comprehend its abilities, fascination over the device grew. In conjunction with the determination that the mechanism was an analog computer of sorts that could predict astronomical phenomena like the positions of stars and eclipses, conjecture over the origins of the device led to theories over what the Romans were going to do with it, and whether the device was created by the Greek genius Archimedes himself. To this day, debate continues over whether there were predecessors to the model, where the astronomical observations that went into creating the model were taken, and whether the ultimate origins of the device might even be Babylonian.

Although tentatively cleaned, the mechanism consisted of little more than a small collection of indeterminate objects encrusted with limestone over most of their outer surfaces. Where the principal fragments had cracked, a blue/green of copper chloride blended with the red of copper oxide, and with various shades of tin oxide mingling to reveal just the faint and enigmatic traces of a tangled mechanism within. The largest fragment, measuring about six by five inches, held a large four-spoked wheel, almost the size of the fragment itself, into the diameter of which had been cut about 200 teeth. A second and smaller toothed wheel appeared to engage with the larger, while several additional cogwheels were visible on the back. Inscriptions were also visible, although not at that point decipherable.

A second, slightly smaller fragment appeared to have a flat sheet of bronze attached to it, upon which were also engraved a series of inscriptions. On the

back of this had been cut a series of concentric circles, which seemed from initial observation to serve as guides for a rotating pointer.[1] In total, at least 15 interlocking gears were visible.

The mechanism's scale, therefore, strongly suggested 360 degrees of the Greek zodiac, with twelve signs running clockwise around its edge, and with the additional likelihood that a pointer of some sort traced the dial in order to mark the Sun's annual movement, as perceived at the time. The outer ring, in the meanwhile, was divided into 365 segments, inscribed with the month name Pachon (ΠΑΧΩΝ), as initially identified by Rehm, and the first two letters of Payni (ΠΑ . . .), or two consecutive months of the ancient Greco-Egyptian calendar visible in the surviving top portion.

Additional inscriptions etched into the scale, and which were only partially decipherable, appeared to refer to such astronomical events as "Vega rises in the evening", "The Hyades set in the morning" and "Gemini begins to rise."[2] These inscriptions were immediately familiar to Price from the various parapegma that he had studied in the past, their typical purpose being to relate these repeating astronomical events with annual phenomena taking place on Earth, such as seasonal shifts, rainfall patterns and the flooding of the Nile. [3] Obviously, the inscriptions on the Antikythera mechanism had been intended to serve a similar purpose.

On the back of the mechanism, in the meanwhile, were two dials, one above the other, the function of which Price could only guess. Each seemed to comprise a series of concentric rings, perhaps five above and four below, divided into segments of about six degrees each. Upon these segments were inscribed strings of letters and numbers whose meaning was unclear, and on each back dial there was offset a miniature dial. The inscriptions on the back of the device seemed less coherent than those on the front, with the few legible words suggesting that these were some sort of operating instruction peculiar to the original owner or user.

The hand that created this extraordinary device would most certainly have belonged to an ancient intellect of staggering brilliance searching for an understanding of the cosmos. The pointers on the front of the casing indicated the changing positions of the sun, the moon and the planets in the Zodiac, with the additional indication of the date and the phases of the moon, while

the spiral dials at the back indicated the month and the year according to the combined lunar/solar calendar, ultimately predicting the timing of lunar and solar eclipses.

Other automatons are known from descriptions, and others worthy of mention include hydraulically-driven birds that chirped, a boiler that maintained its own heat, a fountain that operated by hydrostatic pressure, and another boiler which maintained a hollow sphere in a state of continual suspension. Then there was the first security alarm, essentially a trumpet that blew when a door was opened. A trumpet was attached to a semi-spherical container that sunk into a vessel of water when the door was opened. The compression of air in the container, in turn, caused the trumpet to sound.

One of the most famous ancient automatons was mentioned by Homer. He wrote of tripods "with golden wheels that could automatically enter the assembly of the gods and again return to their residence." These marvelous serving machines were supposedly built by Hephaestus, the divine artisan, who also fashioned a pair of maids out of gold. It is interesting that Homer wrote of mechanical automatons. Surely the Olympian gods would employ live servants to supply their needs or procure them supernaturally, so why the reference to a wheeled automaton? Was Homer referencing a machine that actually existed? Researchers have determined that such a serving robot could be constructed using the technology known to the Greeks. The device would likely be constructed from three rods on three wheels, with a bowl at the top with whatever food items the "gods" wish. The energy required to move the device would be supplied by a cylindrical clepsydra carried between the poles and a lead weight sinking in millet. The axles for the wheels would be moved by 3 kinds of rope circumvolution. Ropes would have been used to program the machine to stop where it was required. It would be truly remarkable if this hypothetical serving robot existed in the age of Homer. He wrote the *Iliad* probably in the 8th century BCE, whereas Philon and Heron, the masters of ancient automation, were not active until the 4th century BCE and the 1st century CE, respectively.

Students of Greek history may recognize the aeolipile as the first known example of a steam engine. This machine was a bladeless turbine named after Aeolus, the Greek god of air. It consisted of a sphere suspended on an axis

above a boiler with water in it. The boiler was heated by a flame, steam entering the sphere by means of two pipes. The pressurized sphere would release steam through two nozzles. The steam produced rocket thrust and thus the ball spun. As interesting as the aeolipile is, it does not seem to have had any practical purpose. No writer attributes any purpose to it, so it seems to have been little more than a curiosity. Its construction, however, does beg the question of whether Heron and other Greek engineers saw the possibilities in steam engines to accomplish useful work. It seems difficult to accept that a genius like Heron, who was likely aware of the invention of the steam cannon, could not see potential uses for a steam engine. Historians are still curious as to why an ancient age of steam, which could have launched the world into a technological age 2,000 years before the Industrial Revolution in Britain, did not begin in the Hellenic world.

One of the Greeks' most famous inventions is none other than the library. In the modern world, libraries are taken for granted by most people, perhaps because their presence is ubiquitous. Every school has a library, large libraries can be found in every major city, and even most small towns have public libraries. However, the omnipresent nature of libraries is a fairly recent historical phenomenon, because libraries were still few and far between before the 19th century. For centuries in the Western world, during what is known as the Middle Ages, written knowledge was guarded closely and hidden away in private repositories, usually by the religious classes, and hidden away in private repositories.

The lack of libraries in the West has helped contribute to the popular imagination of the ancient Library at Alexandria, and all the myths and legends that have come to be associated with it, but the Library of Alexandria deserves its reputation. Before the Middle Ages, Greek scholars carefully collected and inventoried books and other written materials in the Library of Alexandria, which truly made it a sort of precursor to all modern libraries. In fact, the Library of Alexandria proved to be one of the greatest institutions created in the ancient world because it influenced the minds of countless people in profound ways for centuries. The Library not only inspired the imaginations of artists but gave birth to new research methods, which proved to provide the basis for many considered common-place today. The Library of Alexandria was one of the few libraries in the ancient Greek world, which

helped ensure that mathematicians, scientists and other scholars from across the Mediterranean traveled to Egypt to study there, and it was so impressive in its size and influence that it left an indelible mark on the world that still reverberates today.

While the exact nature of the Library remains murky, it functioned for at least several centuries and is believed to have housed hundreds of thousands of books, most written as scrolls on papyrus, and it essentially became the culmination of two ancient literary and cultural traditions converging: the Greek and Egyptian. Of course, the most controversial aspect of the Library of Alexandria is its destruction, which is still a topic of debate today. Several ancient historians attributed its destruction to the Roman conquest of Egypt during the 1st century BCE, with some like Plutarch specifically citing Julius Caesar's soldiers as the ultimate cause of its destruction. The Roman writer Seneca wrote that 40,000 books were lost in the fire. However, other ancient historians claimed to have gone to the Library of Alexandria after Caesar stayed in the city, and all of these claims might be muddled by the fact that there was more than one library in the area. It's possible that the Library of Alexandria or some version of it survived until the 7th century CE, but either way, the destruction of the library is often viewed as one of the reasons the Middle Ages were "Dark". Nobody knows for sure how much knowledge was lost in the Library, nor how it affected what Western societies knew and didn't during medieval times.

The ancient Greeks also had an established literary and writing system before the Library of Alexandria was built, but theirs was not nearly as long as the Egyptians. The Greeks developed writing much later than the Egyptians, and thus their tradition of book keeping and librarianship also took place later. The first form of writing to be used on the Greek mainland is known today as "Linear B script", a form of writing the archaic Greek language in a hieroglyphic-type script utilized during the late Bronze Age (ca. 1400-1200 BCE) (Preziosi and Hitchcock 1999, 3). However, the use of Linear B writing died during the collapse of the Mycenaean culture around 1200 BCE (Parker 2001, 310). The mysterious Sea Peoples invasions, which took place from around 1200-1000 BCE, brought the collapse of many Levantine city-states, the Hittite empire, and nearly toppled the Egyptian New Kingdom before it was over (Sandars 1987, 29-49), and the result was a

general “dark age” in the Mediterranean region, where many of the technological discoveries of the Bronze Age, including writing, were lost for several centuries in some places.

Writing was revived in Greece in the 9th or 8th century BCE when the Phoenician script was introduced and adapted to the Greek language (Parker 2001, 310). The modified Phoenician script proved to be much more adaptable compared to earlier written scripts such as Egyptian hieroglyphs and the cuneiform script employed by the various cultures of ancient Mesopotamia. The scripts of Egypt and Mesopotamia were bulky and could be confusing, especially in the case of the Egyptian hieroglyphs where symbols had both phonetic and idiomatic characteristics, while the new script of the ancient Greeks was more evolved with its simplicity because there was a finite number of letters and each letter was syllabic/phonetic. This script allowed the Greeks to write great works of literature still read today, and it also gave birth to the Latin alphabet, which most modern Western European alphabets are based on.

The process from the discovery of writing in ancient Greece to the creation of the Library of Alexandria was long and somewhat circuitous. Greek classics such as *The Iliad & The Odyssey* were recited orally for centuries before they were finally put into writing, but the copying and collections of those classics represents the nucleus of Greek librarianship. The first evidence of Greek schools can be dated to the 6th century BCE (Platthy 1968, 66), but by the 5th century BCE, schools had become commonplace in Greece and rudimentary book editing had begun to take place. Around that time, a man named Democritus compiled a lexicon of Homeric words in order to better understand and study the works of Homer (Platthy 1968, 83). In fact, by the 5th century BCE, many individual Greeks had amassed private library collections of all literary genres (Casson 2001, 23), and the number and size of those collections increased during the 4th century BC as more books were copied (Casson 2001, 28). As a result, scholarship and the accumulation of knowledge in the form of books were common in Greece by then.

The first private Greek library that approached the standards of the later Library of Alexandria in terms of organization was that of the Athenian

philosopher and scientist Aristotle (384-322 BCE) (Wright 1977, 183). Aristotle, who learned from Plato and was the tutor of Alexander the Great, influenced many in the Greek world with his intellect and philosophical works, to the extent that libraries began to spread throughout the Greek world in the period after his death. This coincides with the period that historians have termed the "Hellenistic period" (Fox 2001, 392), which gave birth to many great historians, philosophers, poets, and even the city of Alexandria itself.

Despite its eventual demise due to neglectful Roman hands, the Library of Alexandria continued to inspire humans throughout the world for centuries, influencing later generations in ways that were both tangible and intangible. Perhaps the greatest gift the Library gave to the world came through Callimachus' invention of the first book classification and ordering system. Callimachus' system can be traced to the modern day through not only the Western Middle Ages, but also through medieval Islamic culture (Heller-Roazen 2002, 144). In particular, the 10th century Iraqi scholar, Ibn al-Nadim, wrote an index very similar to Callimachus' work (Heller-Roazen 2002, 144). Eventually, the Tables of Callimachus would provide the foundation for the modern day Dewey Decimal Classification system that library patrons take for granted.

But it was not just a system of library and book classification that was born at Alexandria. Scholarly terms such as "philologist," "critic," and "grammarian" first acquired meanings similar to the modern ones in the Library of Alexandria (Heller-Roazen 2002, 151), and it was within the halls of the Library of Alexandria that scholars were able to use the Socratic Method and the ideas of Aristotle in a systematic way that is still echoed today in the halls of academia. Maybe the most enduring influence of the Library of Alexandria was in the idea, sometimes fabricated, that it was some sort of ultimate repository of knowledge.

The Library of Alexandria was viewed by many as a symbol of learning even during its existence, but during the European Renaissance the image became more exotic to a certain degree (Bagnall 2002, 361). Scholars began to view the Library of Alexandria as more important than it was, especially when it came to associating arcane and esoteric knowledge with its collection

(Theim 1979, 514). As made clear, the different views of the Library of Alexandria throughout the centuries have evolved to the point that the Library, and its proper place in history, has often been viewed in a more idealized or romanticized image that is not always consistent with reality or historical facts. One only needs to look at the most popular theory of the Library of Alexandria's destruction – during the Civil Wars at the hands (albeit indirectly) of Julius Caesar – to see how this view of the Library has taken hold of the modern imagination. The drama of the Civil Wars and the relationships between Julius Caesar, Cleopatra, Mark Antony, and Octavian have been dramatized in the West for millennia, most famously by William Shakespeare, but also by Hollywood in more recent decades. The Library of Alexandria was never used as a major plot device in any of these fictional accounts, but it is part of the setting in grand epics where historical facts meet literary fiction.

Completed in 2002, the Bibliotheca Alexandrina commemorates the ancient library. Like the Great Library of Alexandria, it aims to collect all the literature of the world, both in printed and digital form. When it was launched, it possessed 10 billion web pages and had shelf space for 8 million books. The new Library of Alexandria will probably never attain the legendary status of the original or come close to its long-term influence on the minds of later generations, but its very existence is a testament to power of the first Library of Alexandria as it continues to enthrall and inspire the imaginations later generations.

Communications and Observations

The Greeks were obsessed with perfection and precision, and they achieved glory in imitating the perfection of nature. The Greeks were particularly assiduous in the measurement of time. Their basic method of computation was very similar to modern society's, as well as that of other ancient civilizations. The year was divided into 12 months, with four seasons, a vernal and autumnal equinox and summer and winter solstice. However, in common with other Mediterranean civilizations, they measured a day over 12 hours, from sunrise to sunset. They used two kinds of clocks: sundials and hydraulic clocks. With sundials, the time was indicated by the shadow of the pointer, which could be fairly accurate but only while the sun shone.

Hydraulic clocks, on the other hand, were not dependent upon the clear sky for their accuracy.

The Greeks used a wide variety of sundials. Hemispherical sundials were concave cavities carved into blocks of stone marked with 11 hour-lines 15° apart. Three curves followed the sun in relation to the solstices and equinoxes. The gnomon, the part of the sundial which casts a shadow, was located in the center. In the spherical sundial, such as that designed by Aristarchus, the gnomon is placed horizontally, making the timepiece somewhat more functional. The quadrantal sundial compensated for the slope of the terrain it was on by being angled between 37° and 40°. Another kind of sundial was a solid sphere which stood south and was marked with 13 lines to mark the hours of the day and others to mark the equinoxes and solstices. Other sundials were cylindrical or spherical concaves: others were horizontal with level tops, with a side marked, or else vertical with a web-like network of lines. Indeed, there were so many different varieties of sundials that the Roman playwright Plautus (d.184) complained that the day was “chopped into pieces” by sundials.

There were even portable sundials that might be carried about rather like watches. One variety was essentially a ring inside a ring, where the inner ring was rotated 90° to indicate the month and the outer ring indicated the hour of the day. The device was suspended vertically. A simpler kind of portable sundial consisted of a flat circle with a gnomon attached and, like the first sundial, was suspended vertically. The simplest kind of portable timepiece used by the Greeks was little more than a four-sided rod with notches carved into the surface, with a handle attached. The Greeks could not claim the credit for this, as the Egyptians used it many centuries before they did.

The simplest form of the hydraulic clock was the clepsydra, consisting of two ceramic cups with inclined sides. The slightly smaller cup, marked to count the hours, was suspended over the other. Water would drip through a small hole into the large cup and would measure out a complete 12 hour period. In an elaboration of this device, the upper cup was replaced by a vertical cylinder with a pointer that marked the hour on a stick as it descended.

Naturally, the Greeks rapidly built on such simple timekeeping instruments

as the clepsydra to create machines unrivaled in precision and elegance until early modern times. Ctesibius was an engineer and mathematician who lived in Alexandria, Egypt, in the 3rd century BCE, and he invented an automated water clock which could not only indicate the hour in a 24 hour (rather than a 12 hour) period but could count 365 days in a year. It involved three vessels of water and a set of gears that moved a pointer, which in turn indicated the time on a rotating drum. The working parts, except for the cylinder, were encased in a vertically- standing rectangular box.

Archimedes created a clock even more complex than that of Ctesibius in that it not only measured the hours of the day but sounded when the new hour came. When the new hour started, the pupils of a mask rolled into place, while a metal bird dropped a ball onto a wood surface. At the same time, a whistling sound was produced. All the while the sounds of gears and flowing water were also heard.

One might wonder whether an engineer who could create a ticking clock might also devise an alarm clock, and indeed several types of hydraulic alarm clocks are known from ancient times. In the 4th century BCE, Aristotle constructed a relatively simple one. It consisted of three buckets, two being around the same size and filled with water and the smallest being empty. The first bucket was elevated on a stand and water flowed through a tap from this to the second, lower bucket. The water level in the second bucket rose and caused a floating pan, upon which rested a number of metal spheres, to rise above its rim. The balls would then fall into the smallest, empty metal bucket, creating a deafening sound. The great philosopher apparently constructed it to wake him at a designated time so that he could study. Plato’s alarm clock, also designed in the 4th century BCE, used four pots of water positioned vertically above each other, and water would pour from the highest pot to the next. When the water poured into the third the volume of water compressed the air in the pot and forced it out through the mouth of a mechanical bird, thus creating a chirping sound similar to the sound of a modern car alarm. The water would then flow into the bottom container.

Ctesibius, not to be outdone by either Plato or Aristotle when it came to hydraulic technology, produced an instrument that is now called a water organ. As the name suggests, it expelled air through a series of pipes to create

sounds. A wheel turned by a water operated pump which in turn compressed air and expelled it into the musical instrument. This hydraulis, as the ancients called it, was not a timepiece, though it could easily have had an application as an alarm. It does not seem to have been originally intended to be a musical device either, as the original model did not have any kind of keyboard attached, nor any method of modulating the sound. Nevertheless, later generations did attach a keyboard and the water organ became a very popular instrument in Greek and Roman times. Indeed, hydraulic organs continued to be used right up until the end of the 17th century.

The technology for measuring was also very advanced. Perhaps the most famous Greek invention in this area is the road counter or odometer invented by Heron in the 1st century BCE. It is also believed that some kind of device for measuring distance was used in the army of Alexander the Great in the 4th century BCE. This is suggested by the accuracy of the records kept by the bematists, or distance recorders, appointed by Alexander. When these are compared to modern readings there is a very small discrepancy. However, scholars have no idea what these instruments, if they existed, might have looked like.

This is not the case with the odometer of Heron, for which researchers have good descriptions. This device was composed of gears and screws contained within a box attached to a moving vehicle such as a cart. An axial rod carried the motion to an eight-toothed gear wheel, and the distance was indicated by three discs located on the surface of the box. The gear ratio in reconstructions of the odometer is 1:8:30:30:30, the last gear rotating once every 1,080 kilometers. Heron also designed an instrument for measuring distance on the water. It consisted of a box of connected gears attached to a large paddled wheel. It was either attached to the side of a boat or floated behind it. As with the land odometer, the distance traveled was indicated by a disk.

The Greeks' skill in measuring the movement of the heavens is legendary. The dioptre was a sighting tube used to record the position of stars and other astronomical objects, as well as for surveying. The 4th century BCE mathematician Euclid described it as consisting of a toothed rotatable disk mounted on a stand and a theodolite on the stand. The operator could aim it at any point in space. This was not, however, the invention of Euclid but, again,

a product of the genius of Heron.

Accurate though it was for the time, it was replaced in the 2nd century BCE by the armillary sphere of Eratosthenes. This instrument was a spherical astrolabe, containing within its skeleton of graduated metal circles a model of the universe as it was known to the Greek world. It represents the poles, the equator, meridians, parallels, and ecliptic, and shows the Earth at the center around which the heavenly bodies orbit. Until the 17th century, when the telescope was invented, the sphere remained the primary instrument for calculating the movement of the stars, and the geocentric model of the universe was accepted as sacred dogma. The 2nd century CE Greek astronomer and geographer Claudius Ptolemy used a modified instrument which he called an astrolabon, from which the English term astrolabe comes.

Greek precision when it came to calculating and measuring distance necessitated an equally precise method of communication over distances. It became vital, especially in times of war, for the poleis to be able to communicate with one another efficiently and quickly. The establishment of a network of fiery beacons occurred fairly early on, but the engineers Kleoxenos and Dimokleitos refined this method of communication in the 3rd century BCE with the addition of a digital element, and the system they produced was unsurpassed until the 16th century. They built beacons on mountains selected for their location and visibility. Each beacon consisted of two walls, each about 6 feet high, with five holders for torches on each. Between the walls were five boards with the letters of the alphabet inscribed on them: 5 per board, except for the last which had 4. The number of torches lit on the left wall indicated the board, while the number on the right wall indicated the letter on that board. In this manner, the operator could transmit words and entire sentences. The signals were observed through a pair of mounted binoculars.

Even more ingenious, though perhaps not as practical or precise, was the “hydraulic telegraph” of Aeneas Taktikos in the 4th century BCE. Telegraphs, cylindrical containers of water, were positioned on high ground. At a prearranged signal from the distant messenger, i.e., the raising of a torch, the receiver would begin to empty water from a cylinder. As the level fell a rod gradually descended. At the same time, the transmitter would also empty

the water from his cylinder. The rods of these cylinders were inscribed with certain messages set equidistantly and each rod was inscribed in exactly the same way. Such messages might be “the enemy has entered the country” or “we have defeated the enemy.” Once the desired message had arrived at an indicated point in the cylinder the transmitter would raise his torch again as a signal to stop emptying. The receiver would raise his torch to indicate he had done so. The receiver should then have been able to read the exact message that had been sent. The obvious drawback to such a system, wonderful as it is, is that transmissions are limited to those that can be transcribed onto the rod. The method would also seem to have been slower than the positioning of torches.

The acoustic telegraph, a curved trumpet about 10 feet long and suspended beneath a tripod, was perhaps a simpler and more obvious method of transmitting signals, yet there is a suggestion that it may have been more than a mere transmitter. As the trumpet freely hung and could be turned anywhere it might have functioned as a primitive radar, being able to locate sounds such as the approach of an enemy army. This device was used by the army of Alexander the Great and had a range of about 2.5 miles.

The Greeks devised methods of sending coded messages as well, which were important for diplomatic communications and especially in times of war. One such method consisted of the threading of a cord through holes in a disk. Each hole on the periphery of the disc would correspond to a letter of the alphabet. Another hole, in the center, represented the letter Alpha. The length of the messages in these discs would be limited by the length of cord, and more complex messages might be conveyed by means of a pair of wooden plates hinged together. The insides of these were coated with black wax, upon which messages were inscribed by a stylus. One code for messaging consisted of substituting vowels with dots, and another utilized mirror writing. In the case of one frantic messenger, the Spartan Dimaratos, the message “Xerxes [the Persian king] is going to attack Greece” was written on the underside of the wax slab.

On the subject of communication, it would seem opportune here to mention thoroughfares in Greece. Surprisingly, the Greek genius for technology was not applied to roads, for a number of reasons. Firstly, they were expensive to

build and maintain, as present-day civil engineers and city authorities would attest. Moreover, the hilly terrain of Greece presented logistical challenges to engineers, perhaps not physically insurmountable in themselves but certainly so given the costs involved. More significantly perhaps, the regions of Greece were ruled by the independent city-states and not by a unified state (at least not until the coming of the Macedonian Empire in the 4th century BCE). At a time when the citizens prized the glory of their polis before that of Hellas, it was hardly likely that materials and fortunes would be expended building a road network that would also benefit rival cities. In any case, only the wealthy tended to travel, aside from pilgrims heading to the shrines of the gods. Those that could afford to travel bought or rented horses and might ride with escorts. For the purposes of trade, cities preferred to use the sea routes, and as most cities possessed a harbor or access to a river there was rarely any difficulty.

That said, roads did exist, although mostly just dirt tracks. However, some of the more well-traveled routes were paved in some form or another. The Diolkos (a word which means “portage machine”) was one such thoroughfare, running across the narrow Isthmus of Corinth from the Gulf of Corinth to the Aegean Sea. This road was used to transport goods from the Gulf to the Aegean, sparing merchant vessels the perilous journey around the Peloponnese. In times of war, it could also be used to transport galleys overland. It was first used around 600 BCE and was abandoned in the 1st century CE. It was about 5 miles long and paved with limestone. It had parallel grooves in it about 1.6 centimeters wide, constituting a primitive form of railway track, since the wheels of a vehicle cannot leave the grooves. The grooves are also interesting in that they assume all vehicles using the road are built to purpose, which in turn suggests a form of technical regulation.

The Greeks may not have paid much attention to rural roads, but they were certainly not negligent when considering city thoroughfares. Hippodamus of Miletus (498 – 408 BCE) was one of the first urban planners to set his cities on street grids. In his plans for the Port of Piraeus, the port of Athens, the thoroughfares were placed parallel to each other, as in many modern planned cities. Many Greek city streets were planned according to wind direction so that citizens might be cooled in the heat of the day. Cobbled stone would be

set upon three layers of rock, with gutters on either side.

The Rate of Technological Advances

One of the most interesting questions concerning ancient Greek civilization is why Greek technology did not advance further than it did. The potential for an exponential explosion was certainly there, as demonstrated by the fact the Greek engineers were apparently aware of the potential for a steam-based technology. The advent of steam-based machines in 18th century Britain lead to the rapid industrialization of the Western world, yet nothing like that happened in the ancient world.

Some historians and sociologists attempting to answer this question have pointed to the liberalization of education and government in the 17th and 18th centuries, though this consideration seems to ignore that there was a comparable sense of freedom in Greece that was fundamental to its culture (whereas in Europe it was superimposed by rebellion, conflict, and war). Joel Mokyr, an economic historian, has argued that the fragmentation of Europe into multiple states encouraged heterodox thinking, for novel thinkers expelled by their own countries might be received by others. Examples of this might be persecuted individuals fleeing to Britain from France, Italy, Spain, and other countries, but again, this theory ignores the fact that Greece was also a fragmentation of rival politics.

Part of the explanation of the rise of the Industrial Revolution in Europe might be the increased centralization of governments in the 17th and 18th centuries. Powerful governments needed income and resources and would encourage industry and innovation to procure those. The Greeks did not have a centralized government until the start of the Macedonian Empire.

The technological moderation of the Greek city-states appears all the more peculiar when compared with the Italian city-states of medieval and early modern times. Like the Greek cities, the Italian states focused on trade, and the wealth generated gave rise to a class of people with the leisure to devote themselves to science and engineering. Renaissance giants such as da Vinci and Galileo ironically relied on ancient Greek studies for their work. In Greece, the wealth allowed the development of technology as well, but unlike in Italy, it did not continue to progress.

Some writers have attempted to answer the problem by suggesting that engineering and mechanics were looked down upon as lowly arts, the province of workers and slaves. According to this idea, educated Greeks were simply not interested in the technological application of ideas. True philosophers sought to devote themselves to the realm of pure thought, much in the manner of modern theoretical physicists. Yet this explanation hardly seems hard to believe, especially since Greek philosophers did not compartmentalize disciplines of thinking as people do today. The philosophers like Plato and Aristotle devoted themselves to the questions of the cosmos as an integral whole, so a a natural philosopher was also a mathematician and an ethicist and a metaphysician and a technologist, and so forth. It seems unlikely then that thinkers would not see the practical application of a particular theory or would not be interested in its practical application, especially if it would benefit civilization.

Nonetheless, the explanation, or part of an explanation, might very well be a philosophical and cultural one. The ancient Greeks conceived of techne as imitating and complementing nature, not supplanting it. They also sought perfection and beauty in everything, so if a machine could imitate nature harmoniously, there would have been no desire or necessity, in the Greek mind, to improve upon it. This idea can be contrasted with the European notion – shaped by Christianity, and in particular Protestant Christianity – that humanity was above nature and was its master. In this view, humankind is the summit and apex of the created order. Nature may thus by be subdued and harnessed to the service of humanity in a manner that would have been quite alien to the Hellenic mind.

In addition to this, there are other, more concrete reasons for the lack of technological progression in the ancient Greek world. Like most other ancient civilizations, the Greek city-states relied upon slave labor, and so long as there remained an abundance of slave labor, there was little incentive to develop labor-saving machines. The ancient Greeks did not have the concept of mass production, with most industries being small concerns rarely employing more than 40 men, and if the Greeks had decided to mass produce technological goods they probably would not have been able to do so for long.

In 27 BCE, the Romans conquered the Greek peninsula. It has been noted that Greek culture conquered its conquerors, but the Romans would have hardly allowed the Greeks to retain technologies that would make them powerful. As it happened, much of Greek technology did become Romanized, but the Romans, like the Greeks, rose on the backs of slaves and saw no utility in technology beyond its immediate application to the service of the Roman people and army.

Given what the Greeks were capable of, it's certainly possible for speculative writers and historians to posit an alternate history in which Greece defeats the Romans with superior technology (perhaps steam-based) and went on to dominate Europe. With that said, it's important to remember that Greek culture was heavily absorbed by the Romans, who preserved it without greatly developing it. The Roman Empire passed it onto its European successor states, which in turn preserved it until the Renaissance and Scientific Revolution, whereupon it exploded and created the world as it exists today.

Online Resources

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[3] *Parapegma* – an antecedent of the modern day almanac. Originally a table relating star phases to corresponding weather predictions. Early versions were carved on stone, and had holes next to the descriptions, marking each day. The peg could be advanced each day, and on appropriate days the associated inscription would "predict" certain astronomical and meteorological events.